GOV DOC
BRA
168

Gov. 96-564

Property of
BOSTON REDEVELOPMENT AUTHORITY
Library

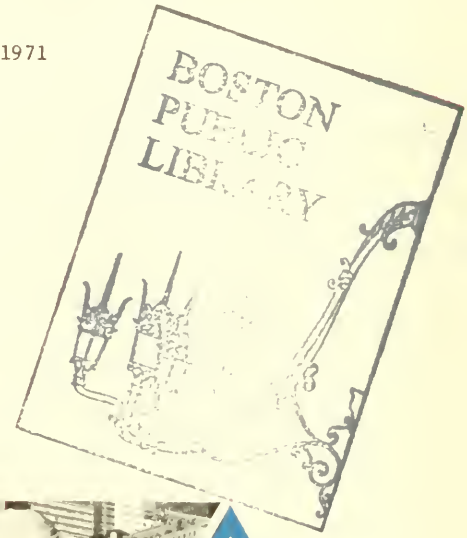
A MOVING-BELT PEOPLE MOVER FOR COLUMBIA POINT

John Murray Malarkey, editor

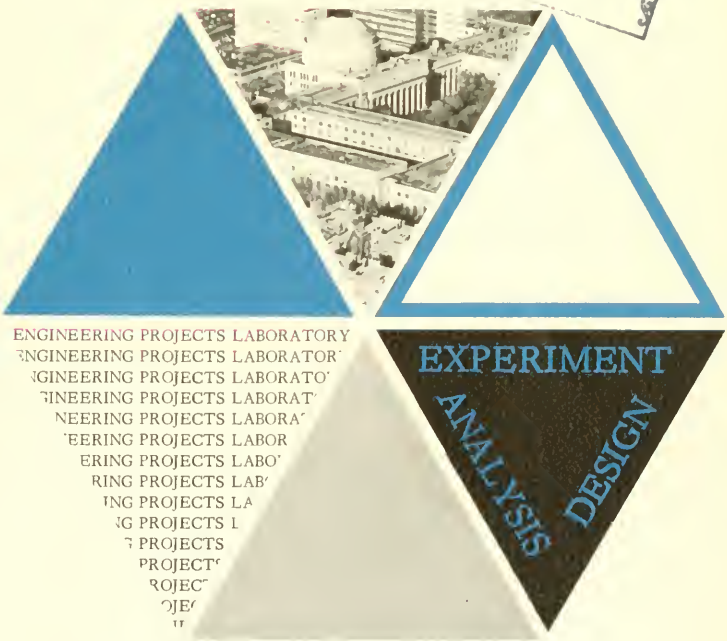
A report on a term project by students
and faculty involved in the Urban Laboratory
in Mechanical Engineering

EPL-2.67 · 1971

June 1972



BOSTON REDEVELOPMENT AUTHORITY
Library



Columbia Pt.
M382 I

Massachusetts Institute of Technology

A MOVING-BELT PEOPLE MOVER FOR COLUMBIA POINT

John Murray Malarkey, editor

A report on a term project
by students and faculty involved in
the Urban Laboratory in Mechanical Engineering

Department of Mechanical Engineering
Engineering Projects Laboratory

ABSTRACT

A people-mover consisting of a relatively high-speed (about 10-m.p.h.) moving belt and seat was designed, and a prototype accelerator constructed, as part of an urban laboratory in mechanical engineering. The system is primarily intended as a link to the Boston-area rapid-transit system (MBTA), which could serve as an alternative to automobile or bus transportation for students and staff traveling to and from the new campus of the University of Massachusetts at the eastern end of the Columbia-Point peninsula. Terminal stations of the system would be located at the MBTA Columbia station and the U. Mass. Student-Activities building near the center of the campus. An intermediate station located about the midpoint of Mount Vernon Street would serve the Columbia-Point housing project. The system would be elevated 15 feet above ground level, fully enclosed, and designed so as to add interest, rather than blight, to the neighborhood through which it would pass.

ACKNOWLEDGEMENTS

Departmental academic funds administered by Mr. Charles E. Barringer supported the cost of materials and equipment used in these experiments.

Mr. J. A. (Tiny) Caloggero and his staff of the Engineering Projects Laboratory supplied help, guidance, materials and general support.

Ms. Cindy Burbank provided secretarial support throughout and typed the final report.

Faculty members who supervised student groups and gave background lectures were Julian Beinart, Peter Griffith, and Stephen Loutrel.

Our teaching assistant and compiler and editor of this report was John Malarkey.

Bruce Schwartz, a senior and member of the course, offered valuable assistance in editing the final report.

Many others helped individual students or groups when they were digging for information or supplies on campus and elsewhere. Mr. Martin Podren of Lynn, Massachusetts should be especially mentioned.

The students themselves devoted an amount of energy and enthusiasm to the project beyond the strict academic requirements.

To all of these I express my sincere appreciation.

David Gordon Wilson
course supervisor

TABLE OF CONTENTS

ABSTRACT 1

ACKNOWLEDGEMENTS 2

LIST OF FIGURES 5

INTRODUCTION 6

- The course 6
- The objectives 7
- People-movers 8
  - History 8
  - At present 9
  - "Things to come" 9
- Background 9
  - Columbia Point 9
  - Available transportation 11
  - The problem 12
  - The project 12

SHUTTLE-BUS SYSTEM--COST AND PERFORMANCE ANALYSIS #1 15

SHUTTLE-BUS STUDY--COST ANALYSIS #2 17

ENVIRONMENTAL GROUP: ROUTING, INTERFACE STRUCTURE, SUPPORT AND ENCLOSURE SYSTEM 19

- Summary 19
- Introduction 19
- Design and route criteria 20
- Determining the route 23
- Support-structure design 25
- Designing the interface 29
- Recommendation 30

A MOVING-BELT ACCELERATOR 32

- Summary 32
- Introduction 32
- Method 32
- Conclusions 34
- Recommendations 37
- Faculty comment 37

MOTOR DRIVE FOR PEOPLE-MOVER 40

- Summary 40
- Introduction 40
- Prototype construction 40
- Conclusion 41

HUMAN DETERMINANTS OF SUPPORT-ROLLER DESIGN 42

- Summary 42
- Introduction 42
- Conclusion 44

ESTIMATES OF BELT WEAR 45

Summary 45
Introduction 45
Tests 45
Conclusion 46

EXPANDING-LINKAGE DRIVE SYSTEM 47

Summary 47
Introduction 47
Model construction 48
Testing 51
Conclusion 53
Faculty comment 53

TOLERANCE TO DECELERATION ON A MOVING BELT 54

Summary 54
Experiment #1 54

Introduction 54
Method #1 55
Conclusions 56

Experiment #2 57

Introduction 57
Method #2 58
Conclusion 60
Faculty comment 60

PASSENGER-OPERATED SAFETY ALARM 63

Summary 63
Introduction 63
Description of system 65
Design and construction 65
Conclusions and recommendations 68

CONCLUSIONS ON THE PROJECT 69

BIBLIOGRAPHY 70

LIST OF FIGURES

1	Columbia Point and possible people-mover routes	10
2	University of Massachusetts Boston campus, Columbia Point	13
3	Illustration of test accelerator	33
4	Detail of "interleaved"part of accelerator	35
5	Detail of solid belt at driven end	36
6	Proposed design of full-size accelerator	38
7	Three stages of prototype accelerator	40
8	Detail of motor drive to belt	41
9	Adjustable brackets for support rollers	42
10	Belt droop between rollers at minimum spacing	43
11	Diagram of test apparatus for measuring belt wear	46
12	Diagram of expanding-linkage drive	48
13	Hand pole with linkage drive	49
14	Chair cart with linkage drive	49
15	Possible system for making a 180° turn	50
16	Friction test apparatus	51
17	Results of friction tests on linkage	52
18	Deceleration for step change in velocity	54
19	Sideview of belts and rollers	55
20	Motion on a parallel-plate accelerator	55
21	Acceptability tests for step changes in acceleration	56
22	Test-vehicle-braking mechanism	57
23	Apparatus for scribing timing marks on tape	58
24	Deceleration-test apparatus	59
25	Minimum region of acceptable deceleration	59
26	Theoretical region of acceptable deceleration	60
27	Experimental results of acceleration tests	61
28	Cut-away view of safety alarm	64
29	Flat sections going around drive wheel	66
30	Cross section of switch mechanism	67

INTRODUCTION

The course

Course number 2.67, Urban Laboratory in Mechanical Engineering,[5]* was first offered by the Mechanical Engineering department at M.I.T. in 1967, with the aim of providing undergraduates, regardless of their engineering background or experience, a laboratory project course of a type which had become very successful in the design division of the department. Since then, an over-all theme has been selected each year, and prominent people have been invited to talk about aspects of this theme in one or more class lectures. Members of the teaching staff have also presented lectures on various phases of problem evaluation and design.

The course has evolved through a number of variations over the past five years. The first year's theme was "technological aid to developing countries." After the first four weeks of the semester the class formed into groups of about four students each on the basis of similar (individual) project proposals. After discussion and compromise each group selected a single project. Volunteer faculty advisors were approached, and one was attached to each group. Actual project work commenced about five weeks after the beginning of the term.

In order to shorten this long initial period (during which time the interest of some students waned), two changes were instituted the following year. The problem--"pollution in Boston"--was chosen in advance by the teaching staff and broken down into ten specific problem areas, also chosen beforehand through discussions by the faculty-member-in-charge with people in local government and industry who would be willing to talk to the class about their fields and to act as non-paid clients for the rest of the semester. Faculty advisors were also lined up in advance, and the six student groups chose projects during the first two weeks of the semester.

The course's format underwent two succeeding modifications. First was the specification of a single, specific over-all problem. Student groups would then address themselves to parts of this over-all problem. In 1969 this problem was the design, construction, testing and demonstration of an "automatic zone-fare ticketing system for urban buses." These student groups learned to appreciate some of the problems of working on a part of a larger system while having to collaborate with other groups working on other parts of the same system.

Second, in 1970, the assignment of tasks was further broken down so that each student had responsibility for an individual problem (and for the solution). The topic, again, was chosen beforehand: the determination of a transportation system from the mainland to Long Island

* Raised numbers refer to references given on page 70.

in Boston Harbor which would allow the island to be developed for recreational purposes. Since there was a single over-all objective, the interface problems were as evident as before. Students were grouped according to closeness of interests and problem areas, to facilitate communication and faculty supervision.

This year's format was similar to last's. In the first weeks of the term the project theme--providing public transportation for students, faculty and staff to the new Columbia Point campus of the University of Massachusetts--was introduced. Frank O'Brien, director of the U. Mass. Planning Office, spoke to the class about different aspects of the problem, and the staff presented preliminary lectures on problem analysis, system design, and model construction. After about four weeks each student submitted his own solution to the problem in the form of a project proposal. One proposal was selected by a committee of faculty and students, and this became the project for the semester. The project was broken down into specific problem areas; each student then chose one from the list, and faculty members were assigned to advise groups of three to five students in related fields.

The objectives

The project selected for the course (from student proposals which included variations on rail rapid transit and bus systems) was the design and prototype construction of a moving-belt people-mover for transporting students and staff to the new campus of U. Mass., Boston. The project was divided into seven general areas of study:

1 - route determination,
2 - human factors and engineering,
3 - station and guideway design,
4 - methods of acceleration,
5 - belt support and wear,
6 - economics, and
7 - safety.

Relatively few constraints were placed on members of the class, in terms of theoretical work, the financial budget being the greatest restriction. It was assumed that the people-mover would have a station at U. Mass., but it was not specified whether this would be a terminal station or a location on a transit loop. Nor was an origin for the system specified, or whether the system would serve any passengers other than those bound to or from U. Mass. These were to be class decisions.

The capacity was based on estimates by the U. Mass. Planning Office of the need for a 1980 peak capacity of 10,000 people per hour. Route determination had to consider land availability and acquisition costs, environmental impact, and the cost of construction. The system could

not be so exotic as to be financially infeasible, yet it had to be an attractive enough alternative to automobile commuting as to attract passengers. In short, the system was to be a real application to fit a real situation, with very few artificial constraints.

People movers

It is perhaps ironic that the present resurgence of interest in moving-sidewalk people-movers has been motivated by the need to relieve our city streets from the congestion and pollution caused by automobiles, city buses, and trollies, while just some 50 years ago the introduction of these same vehicles caused virtually all technological interest in such moving pavements to cease. Nevertheless, significant research and development was carried out on such systems before the 1920's and these early achievements have been very useful to modern transportation designers and engineers. They provide an interesting background for this report.

History.[3,4] The first known moving platform was proposed for New York City in 1874, and was to run on an elevated track at 15 m.p.h. A series of six-seat trollies ran alongside and could be accelerated or decelerated for interchanging by means of a friction brake. In 1880 Dalifo proposed a system consisting of a continuous series of seats on an elevated structure, which simply speeded up or slowed to a stop at stations. (In theory this system is quite similar to Goodyear's present Carvevor system.)[1] Rettig proposed the first three-speed system in 1888. It consisted of three continuously-moving, parallel platforms rolling on wheels at 3, 6, and 9 m.p.h.

Finally in 1893, at the World's Columbian Exhibition in Chicago, a full-scale moving sidewalk was actually built and operated. The two-speed system followed a great ellipse one-mile long at speeds of 3 and 6 m.p.h. (At the Paris Exhibition in 1900 a two-and-a-half mile system was operated which had two parallel wooden platforms moving at 2-1/2 and 5 miles per hour.) This system ran for eight months and was used by 6-1/2 million people, running for 12 hours a day, carrying daily about 120,000 people, with a total of 40 minor accidents. "It was a great success, and writers of the period, H. G. Wells among them, regarded it as 'a promise of things to come.'"

Further designs and proposals were advanced in the 1920's. In 1920 the City of Paris held a competition for a transit system design to replace the then inefficient Metro. One of the winning schemes was a 10-m.p.h. moving platform with a series of interlocking belts capable of accelerating the passenger from a speed of 1-1/2 m.p.h. up to 10 m.p.h. And a three-speed system was proposed in 1923 to run between New York's 42nd Street and Times Square. Neither of these schemes was ever built. For the next 30 years, very little progress was made in the design or construction of moving pavements.

At present. By the 1950's wooden platforms could be replaced by steel-reinforced, ribbed rubber belts, and moving sidewalks were again "a promise of things to come." The Boston Redevelopment Authority recently completed an in-depth study of the city's pedestrian and mass-transit problems and recommended for immediate action the building of a system of moving walks in the South Station-Summer Street areas totalling almost 4000 feet.[6] Meanwhile cities, hotels, airports, and parking lots around the world are already experimenting with systems such as the Goodyear Speedwalk/Speedramp.[8] By code* these people-moving conveyors can travel horizontally at up to 180 feet per minute or can rise at an angle of 12° to 15° at rates 90-140 feet per minute (1 to 1-1/2 m.p.h.), and carry as many as 10,000 people per hour.

The first Speedramp system was installed at the Chicago Museum of Science and Industry in 1952, and is still in use today. The longest moving walk in operation is a 700 foot length in Sydney, Australia; most of the approximately one-hundred-and-fifty other installations around the world are less than 100-feet long. Over half of the known installations creep along at 90-120 feet per minute, and over 90% run at 150 feet per minute or less, roughly two-thirds of walking speed.

"Things to come." Low speed is the major handicap of present people-moving systems, and the bottleneck in higher-speed systems is development of a suitable accelerator and decelerator. There are approximately 120 new concepts for accelerator beltways being developed in the U.S. and Europe, but only a few have reached the point of actual construction.[6] Likewise an important issue in higher-speed systems, and possibly a more difficult one to solve, are the human-engineering aspects--the question of the adaptability of the human being to the system. Any more advanced systems in the future will first have to overcome these obstacles.

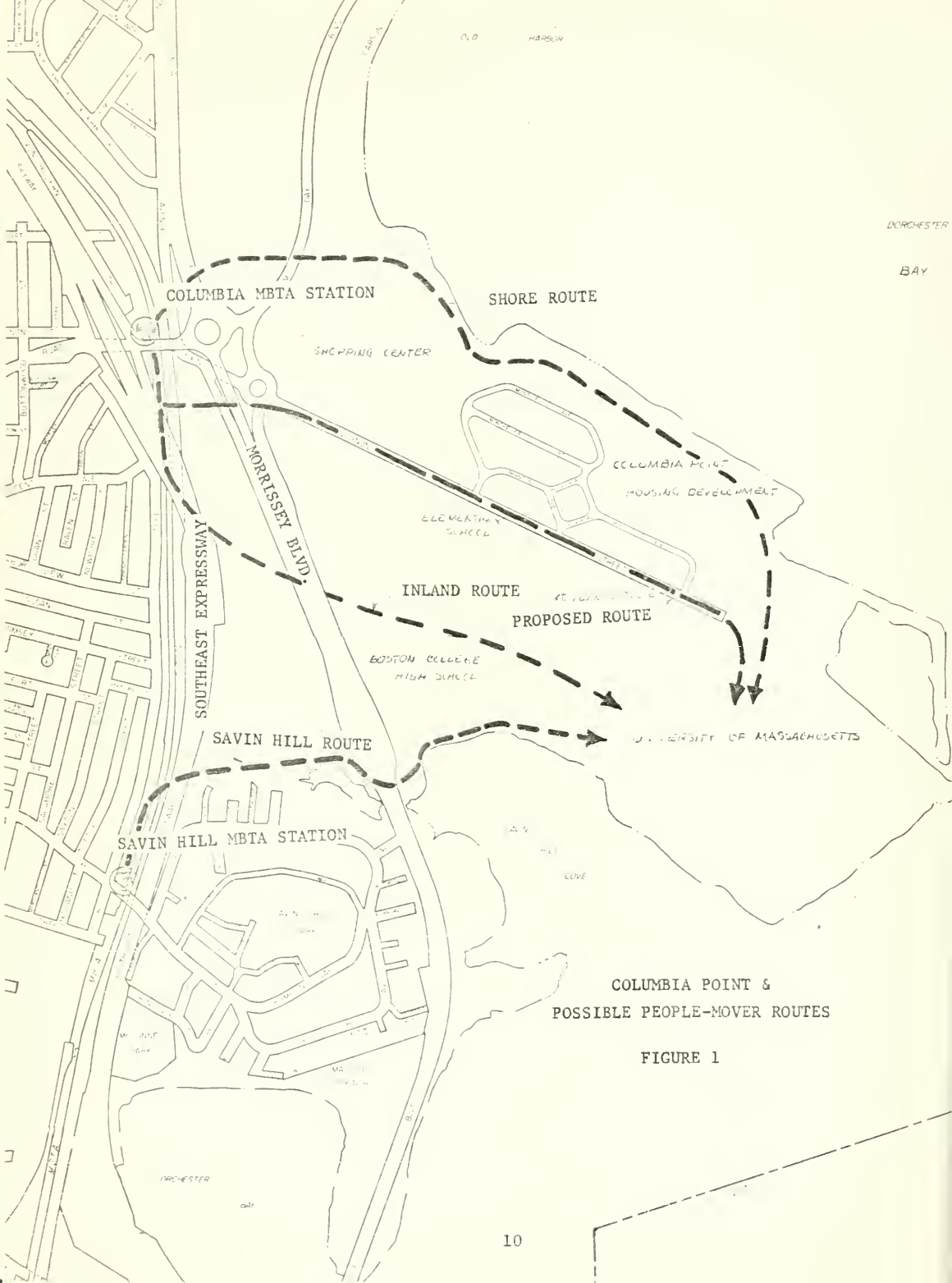
Background

Columbia Point. Columbia Point is a peninsula jutting 1/2 mile out into Dorchester Bay about three-and-a-half miles south/southeast of the central business district of Boston (fig. 1). Much of its mass is solid land fill, and a fortresslike, obsolete sewer-pumping station still squats in a closed dump adjacent to the site where U. Mass. is under construction, at the end of Mount Vernon Street. The area is low lying, the highest point being less than 40 feet above sea level, and vegetation is sparse.

The peninsula's most prominent feature (until the arrival of U. Mass.) is the Columbia Point housing project, 38 buildings containing 1500 units of low-income housing. Built in 1952, the project mixes high-rise towers with three-story "garden" apartments, all faced with a drab tan-

---

* American standard safety code for elevators, dumbwaiters, escalators, and moving walks[6]



COLUMBIA POINT &
POSSIBLE PEOPLE-MOVER ROUTES

FIGURE 1

colored brick. Landscaping is mostly asphalt strewn with weeds and/or broken glass. The project shares the physical drabness and social pathology of many such federally-subsidized housing projects; the area has high rates of crime and vandalism. The project houses some 6000 residents; the majority are black; many of the white residents are elderly. 3500 are under the age of 18. Only 35% of Columbia Point's families have automobiles, a fact which underscores the community's remoteness from the rest of Boston and from the nearest rapid-transit stop, the Columbia Station, over half a mile away. A single road--Mt. Vernon Street--connects Columbia Point to the rest of the city.

Despite this--and indicative of Boston's shortage of low-income housing--Columbia Point has a waiting list for apartments. It is neither the worst nor the best of the several public housing projects administered by the Boston Housing Authority.

An elementary school on Mt. Vernon Street serves almost exclusively children from the housing project, while Boston College High School, facing on Morrissey Boulevard (which runs along the western boundary of the peninsula), enrolls few Columbia Point students.

A moderately sized shopping center occupies the land to the west of the housing project; on the other side of Mt. Vernon Street are the offices of the First National Bank, the Dickie-Raymord Company, and the studios of WHDH radio-TV, facing on Morrissey Boulevard. A couple of small businesses border the U. Mass. campus at the western end of Mt. Vernon Street, and there is a church and a small ball field across the street from the housing project, adjoining the school. Yards and playing fields behind the schools constitute the only other open land on the peninsula besides the dump; with the completion of U. Mass., all available land on the peninsula with the exception of the former dump will be occupied. This land scarcity was to make route selection difficult.

Available transportation. The area is served by two modes of public transportation at present. The MBTA skirts the mouth of the peninsula, west of and essentially parallel to Morrissey Boulevard. The Red Line, as it is called, follows the route of the Southeast Expressway between the two stations nearest the peninsula, i.e., Columbia and Savin Hill stations, and carries trains of the Quincy and Ashmont lines. Only the latter, however, presently stop at Columbia and Savin Hill stations.

Columbia is the station nearer the housing project; however, walking between the two points requires crossing either Mt. Vernon Street, Morrissey Boulevard and/or one of two heavily trafficked rotaries. The Savin Hill station, less than a mile south of Columbia, is separated from the peninsula by the built-up neighborhood on Savin Hill, and is not within reasonable walking distance of any point on the peninsula.

Bus service is provided by a single MBTA line that originates in Dorchester, stops at the Columbia station, circles the housing project and returns via Mt. Vernon Street to the MBTA station and Dorchester.

A poll taken by Stu Traver of the environmental group of a few (a statistically insignificant number, granted) residents indicated about 30% expressed dissatisfaction with the MBTA service.

The problem. Mr. Frank O'Brien, from the University of Massachusetts Planning Office, introduced the class to the problem at hand and provided some fundamental background information. The school (see figure 2) was to be opened by 1975 with full enrollment of 15,000 students --all commuters--by 1980. With faculty and staff, we could easily expect 20,000 people arriving on campus every school day.* Even with the nonuniform scheduling of students, we could, according to Mr. O'Brien, expect a peak of arrivals during the morning rush hours (to 9 a.m.) and a peak of departures at the evening rush hours (after 5 p.m.)--possibly amounting to ten-thousand people per hour.

From a transportation standpoint, few locations for the new school could have been as unfortunate as the one chosen. The nearest MBTA station, Columbia, is nearly a mile from the site. Few people could be expected to voluntarily negotiate this distance, especially during inclement weather. The school accordingly had planned considerable parking facilities and expected much of its personnel to arrive by car. Those who did use public transportation were to be accommodated, at least initially, by a bus loop running from Columbia station to the campus.

The expected automobile traffic required that a four-lane motor entrance be planned and built, along with an extensive (and expensive) interchange at Morrissey Boulevard. No amount of highway engineering at this bottleneck, however, could be expected to eliminate the impact the additional traffic will have on the boulevard and Southeast Expressway, which already operate at or beyond saturation levels during peak hours.

Only an effective link with rapid transit (the Red Line) could even ameliorate this increase in traffic load, by drawing off people who would otherwise commute by car. To do so, however, the system would have to be competitive with the automobile in terms of travel time, convenience and comfort. These requirements dictated certain corollaries: for example, assuming travel time via MBTA to Columbia station could be competitive with automobile travel of like distance, then travel from the station to the campus had to be sufficiently attractive so as not to discourage riders. This meant, we felt, a ride of under ten-minutes' duration.

The project. Having defined the problem, we considered individual students' proposed solutions. A shuttle-bus system (such as the one U. Mass. will open with) was considered as a practical solution, and a preliminary cost study was completed near the beginning of the term as a basis for comparison with our solution.

* Political developments subsequent to the time these estimates were made (during the semester, in fact) may result in final enrollment being set at a lower figure.

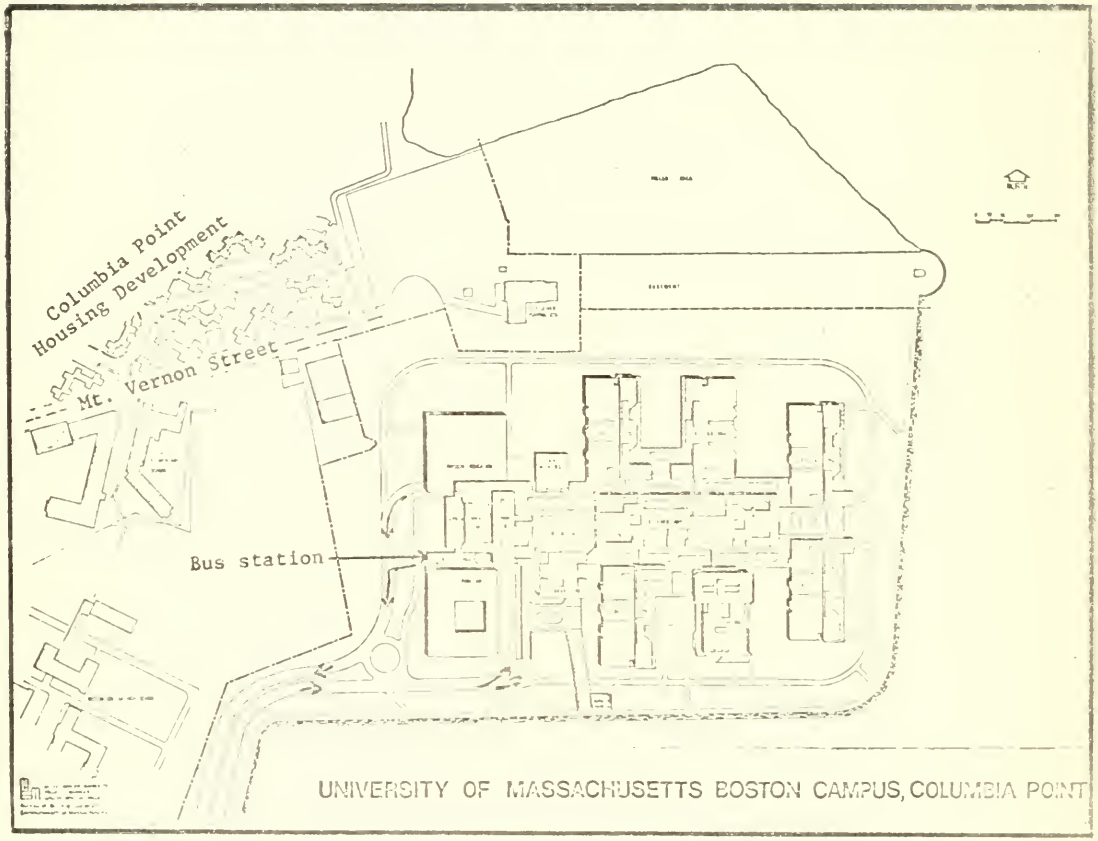


FIGURE 2

(arrows indicate proposed bus routes to and from campus;
bus station is indicated.)

We chose a real situation, i.e., the Columbia Point project, so that we could simulate the problems and processes involved in such an actual undertaking. Even before determining the actual project, then, we had to deal not only with fairly tangible factors (costs, for example) but with such intangibles, nonetheless important, as environmental impact. A high-speed rail link might prove the fastest, most efficient means of transit, for example, but such a line could not be located at grade, and underground construction might prove prohibitively expensive. A system using entirely existing technologies might be most practical, but would offer little in the way of a teaching exercise to the class. The moving-belt people-mover was chosen, not because it was a new concept, but because we felt it offered a practical solution to the problem while offering the students a challenging technical exercise. In addition, there exists to date no high-speed moving-sidewalk system anywhere with an acceptable means of acceleration, and it was our hope that we should make some contribution to the technological advancement of the subject.

The work described here is not, therefore, to be taken as "M.I.T.'s answer to the Columbia Point transportation problem." It is simply one of many possible solutions, examined by a group of nonengineering students, some highly talented, some not so gifted, and none having any previous experience of transportation engineering.

That this group designed, constructed, and tested some of the critical components of the people-mover within the overall time of three months, about half of which was spent learning about transportation and about laboratories, is a measure of the enthusiasm generated by the majority of the students. And as the various transportation planners we talked to had not apparently considered a people-mover link between Columbia Station and the U. Mass. campus previously, while now a contract has been let for the study of such a link, we believe that we might have had an educational effect beyond the confines of M.I.T.

With this introduction, we now present the final reports of the individual students and/or groups.

SHUTTLE-BUS SYSTEM--COST AND PERFORMANCE ANALYSIS*

-Neil D. Singer-

Possible factors to consider:

A ≡ average travel speed of bus (not including stops), mph
C ≡ capacity of bus, people/bus
N ≡ number of buses to be used
S ≡ stop time in each station, minutes
L ≡ loading capacity of each station expressed as the number of buses which can be simultaneously loaded or unloaded
B ≡ boarding rate, people/minute
T ≡ round-trip time, minutes

We wish to determine F, the flow capacity of the system expressed in people per hour, and to determine the relationships between variables. The distance is taken to be 4/5 of a mile with stops only at Columbia MBTA station and the campus bus terminal.

If the average speed of a bus is A mph then it is A/60 miles per minute. Since the bus makes two 4/5-mile trips and two stops per round trip we get the round trip time as:

$$T = \frac{(2)(4/5)}{A/60} + 2S \text{ minutes} \quad \rightarrow \quad \frac{AS + 48}{30A} \frac{\text{hr}}{\text{trip}}$$

We can then express the capacity of the system as:

$$F = \left(\frac{\text{trips}}{\text{hour}} \text{ for one bus}\right) (\text{number of buses}) (\text{people per bus trip})$$

$$F = \frac{30\ ANC}{AS + 48}$$

Since it is pointless to have too many buses--they will just end up waiting in line to use station facilities--we seek the maximum number of buses in terms of the other variables. This can be found by realizing that to make maximal use of all facilities the flow of the stations in buses per hour should equal the flow of the road in buses per hour. Solving this equation for the optimal number of buses to use we get:

$$N = L\left(\frac{96}{AS} + 2\right) = \frac{2L}{AS}(AS + 48)$$

Substituting this number of buses into the system flow equation gives the following:

$$F = \frac{30\ AC}{AS + 48} \cdot \frac{2L}{AS} \cdot (AS + 48) = \frac{60\ LC}{S}$$

Thus we have thenot-so-obvious result that the average speed of the buses does not affect the maximum flow of the system. This seems reasonable when one considers that faster buses would just have to wait longer to be able to use the station facilities.

---

* This is the first of two cost analyses, using slightly differing assumptions Some concluding remarks follow Stuart Traver's (the second) section.

Also L is the only independent variable affecting capacity. N is dependent on it.

Since stop time would tend to be directly proportional to the number of people getting on or off the bus, which is in this case all the passengers, we have:

$$F = 60\ LB$$

Note that it is reasonable to estimate at least one second per person and more likely two or three. For two seconds per person = 30 people/minute we get:

$$F = 1800\ L$$ which means 5 loading platforms are needed per station

Then $N = 5(48/A + 2) = 240/A + 10$ which gives a spread of 34 to 58 buses depending on speed in the range of 5 to 10 mph. This assumes 60 people per bus by virtue of assuming a two-minute boarding time.

To get a cost estimate, I shall choose all factors to be favorable to the system, thus obtaining a very low cost estimate. A more realistic estimate would most likely be 25 percent to 50 percent higher.

Cost for buses:

	MBTA*	here
basic per year	\$15.5K	\$ 8K
plus per mile	\$0.23	\$0.12
plus per hour	\$12.69	\$9.00

Each of 35 buses to be used an average of three hours per day at an average speed of 10 mph:

$$\text{Cost} = \begin{bmatrix} 200 \text{ days} \times 3 \text{ hrs/day} \times \$9/\text{hr} = \$5400 \\ + 6000 \text{ miles} \times \$0.12/\text{mile} = 720 \\ + \text{yearly bus cost} = 8000 \end{bmatrix} \times 35 \text{ buses}$$

$\approx$ 1/2 million dollars per year rock-bottom cost for a system capable of handling enough people at peak periods

To have the MBTA do the job at average speed of 7 mph:

$$N = 5\left(\frac{48}{7} + 2\right) = 45 \text{ buses}$$

$$\text{Cost} = \begin{bmatrix} 200 \text{ days} \times 4 \text{ hrs/day} \times \$12.67/\text{hr} \\ + 6000 \text{ miles} \times \$0.25/\text{mile} \\ + \$15{,}500 \text{ basic bus cost} \end{bmatrix} \times 45$$

$\approx$ \$1.2 million reasonable estimate for MBTA

* From reference 7 ("The finances and operation of the Massachusetts Bay Transportation Authority," the sixth and final report of the special legislative commission on the MBTA, 1971).

SHUTTLE-BUS-SYSTEM COST ANALYSIS

-Stuart R. Traver-

The study predicts estimated yearly operational costs for a shuttle-bus-system linking the Columbia MBTA station with the future University of Massachusetts campus on Columbia Point, based on a number of reasonable assumptions concerning bus-operation time, speed, cost, and capacity. Several values are presented for each of the fixed, mileage, and hourly costs in order to obtain a range of values for the total cost.

Assumptions

1.	Operation year	200 days
2.	Average bus operation	3 hours/day
3.	Average bus speed	6 miles per hour
4.	Length of route (one-way)	1 mile
5.	Bus capacity	60 people
6.	Round-trip time	20 minutes
7.	Initial cost of one bus	25,000 dollars

For the purposes of this analysis we will assume the use of 50 buses, providing a maximum flow capacity of

$$\frac{(50 \text{ buses})(60 \text{ people/bus})}{(1/3 \text{ hour/trip})} = 9000 \text{ people/hour}$$

since this is close to the maximum flow expected to or from the campus.

	per bus	total
FIXED COSTS PER YEAR:	$10,000	$500,000
	12,500	625,000
	15,000	750,000
MILEAGE COSTS PER YEAR:	$0.20/mile	$36,000
	0.23/mile	41,400
	0.25/mile	45,000
HOURLY COSTS PER YEAR:	$10/hour	$300,000
	12/hour	360,000
	15/hour	450,000

TOTAL COSTS PER YEAR (using lowest operational cost estimates):

FIXED:	$500,000
MILEAGE:	36,000
HOURLY:	300,000
OPERATIONAL:	836,000
+10% OF INITIAL COST:	125,000
TOTAL:	$961,000

TOTAL COSTS PER YEAR (using highest operational cost estimates):

FIXED:	$750,000
MILEAGE:	45,000
HOURLY:	450,000
OPERATIONAL:	1,245,000
+10% OF INITIAL COST:	125,000
TOTAL:	$1,370,000

Thus the expected yearly total cost of the shuttle bus system, assuming the initial cost is spread over the first 10 years of operation, lies between $961,000 and $1,370,000.

Bus costs--comments

The two cost estimates, by Neil Singer and Stuart Traver, use slightly different approaches but arrive at similar figures showing that the cost of a shuttle-bus system to carry 10,000 per hour at peak periods would be, on the most favorable possible estimates, half a million dollars per year, and on less-favorable assumptions, $1.4 million.

Neither figure accounts for the costs of boarding platforms or shelters at either end of the trip or at Columbia Point housing project; nor has any account been taken of the external congestion costs which would be caused other road users by the presence of 35 to 50 buses circulating around a comparatively short loop.

These figures were used as targets. A people-mover system would either have to give comparable performance at lower cost, or superior performance at equivalent cost.

ENVIRONMENTAL GROUP: ROUTING, INTERFACE STRUCTURE, SUPPORT AND ENCLOSURE SYSTEM

-Stuart R. Traver, Bruce S. Schwartz, and Lance D. Dickes-

Summary

After consideration of technical, economic, socio-political, and ecological factors, the environmental group proposed that the moving-belt "people-mover" take the form of an elevated structure routed from the Columbia MBTA station to the U. Mass. campus down the center of Mount Vernon Street with an off-line station at the main entrance of the Columbia Point housing project.

The system would provide two five-foot-wide beltways traveling in opposite directions at a speed projected to be about ten miles per hour. The support structure would be elevated a minimum of fifteen feet above all roadways. The Columbia station terminus would replace an existing pedestrian overpass at the south end of the Columbia MBTA station; the U. Mass. terminus would be integrated into the projected student-center-building there. The Columbia Point housing-project station would be elevated and integrated with the housing project by a functional and decorative plaza.

The people-mover would be supported by a double row of regularly spaced concrete pylons, and would be enclosed by lightweight walls and roof, glazed extensively to provide natural lighting. The interior environment would be equipped with heating and air conditioning, lighting, sound and visual-display systems, moving seats and handrails, and an emergency-stop alarm system. The exterior of the people-mover would be a colorful presence in a drab neighborhood, and could be used for graphics or artwork.

To illustrate our proposals, models were constructed of a portion of the people-mover route (Stu Traver), the Columbia Point housing project station (Lance Dickes), and of a sixty-foot segment of the people-mover structure (Bruce Schwartz).

Introduction

The environmental group was charged with three interrelated tasks: to select a route for the projected people-mover; to design interfaces between the system and its loading-unloading points; and to design a support structure and enclosure for the belt system. "Environmental group," then, was something of a misnomer, for in practice we had to consider nearly every aspect but the engineering of the (hypothetical) system. These included macro-design, architecture, economics; social, political and ecological impacts, etc. The proliferation of decisions prevented us from dealing with many questions in a thoroughly rigorous, analytic and quantitative manner if we wanted

to come to grips with the issues at all in the limited time available to us. We quickly--and sometimes painfully--became aware of the interrelatedness of every factor involved in the design of this system; the resulting complexity did not lend itself to straightforward decision. Some issues were resolved almost arbitrarily; under the circumstances, we feel this was probably an accurate reflection of processes which go on in real situations. For example, the decision to serve the Columbia Point housing project is instructive in this regard.

The decision that the people-mover system would serve the Columbia Point housing project as a sort of "extra" feature was made very early in the project, and more by general, implicit concern of the class than by any "logical" process. One could argue, from a coldly tactical standpoint, that serving the project would "buy off" or defuse potential community opposition to a project that might go through their neighborhood. On the other hand, there is a case to be made that, in any event, these people (in the projects) are powerless and inconsequential in conventional political terms. That, however, was not the point for most of the people in the class, who felt it would be an insult and an injustice to construct a rapid-transit link for the university community while ignoring the project tenants, already underprivileged by their income brackets and their address. That a people-mover station could prove a boon to the people of Columbia Point, and that they deserved such a share in the proposed system, was taken almost for granted by the class and was endorsed by us in our process of route selection.

One cannot design in a vacuum. Selecting a route required knowledge of the characteristics of the system, but the system had to be designed as well to fit the contingencies of the route we selected. Station design, logically, would follow from conditions imposed by the route and type of support structure; on the other hand, certain characteristics of the interface would have to be reflected in design of the main structure. As it turned out, we were able to proceed in a fairly logical fashion, step by step (though not until later did we identify our procedure explicitly). We first established criteria for the main-structure design and the route, based upon the capacity and other requirements of the system and the ancillary purposes we wished to serve (such as service to the housing project). After settling on a route and a macrostructure, we proceeded to design, in some detail, the support structure, enclosure, and stations.

Design and route criteria

We had, as "givens," several criteria to start with in terms of capacity and destination of the system. A peak capacity of 18,000 people per hour was demanded; the final destination had to be at the U. Mass. campus; the origin was to be the MBTA. The accelerator group indicated that a series of belts totalling perhaps 150 - 180 feet in length would be needed for accelerator and decelerator strips; this, along with the bunching of passengers which might occur at sections where speed changes occurred, governed interface design to a major degree.

Stuart Traver developed the following set of criteria for the route:

1 - Length and time. We felt that the shorter the perceived trip time, the more likely the system would be to attract passengers. We assumed a constant speed of ten, or so, m.p.h. for the high-speed section of the belt. So length was the governing variable, unless passengers had to walk any considerable distance between modes.

2 - Service to the Columbia Point housing project. Certain of the possible routes would not have been near the project; others would have required considerable walking from users and would not have been very accessible by project residents.

3 - Service to the shopping center. Ultimately this criterion received very low weight, but it could have been a deciding factor between two otherwise-equivalent systems. In the end, we felt that a station to serve the shopping center would not justify its cost in terms of expected use.

4 - Service to the elementary and high schools. The Paul A. Dever elementary school draws most of its children from the Columbia Point project; B.C. High School is not unreasonably far from the MBTA Columbia station and its students manage at present to commute without undue hardship. This criterion, also, was fairly low in weight.

5 - Construction costs. This was a factor in routing because different routes would necessitate different kinds of construction. For example, it would not be possible to construct a people-mover at grade through the shopping-center parking lot without disrupting its usefulness as a parking lot; this would mean building underground or elevated. Similarly, the water table at Columbia Point is close to the surface--meaning drainage problems for excavations. We aimed, of course, to keep cost to a minimum without sacrificing any of our primary aims concerning service and environmental protection.

6 - Land- and property-acquisition costs and availability. This introduced a bias in favor of building on land already city-owned. A more severe restriction was availability. Columbia Point contains no vacant land save the abandoned dump at the eastern tip (not much of a help in bridging the gap between U. Mass. and the MBTA). Much of the land is occupied by buildings, many of a sort (schools, etc.) that cannot be conveniently condemned for a project such as a people-mover. The developed areas of the peninsula further restricted our choice of routes.

7 - Disruption of traffic patterns. This was a particular consideration if the people-mover were to follow the route of an existing right of way, such as Mount Vernon Street. We had to consider to what degree the people-mover would disrupt its use as a motor road. We also had to consider

the effects of various schemes of crossing Morrissey Boulevard. One of these, for example, might have been a pedestrian walkway/crosswalk combination running from the Columbia MBTA station to the origin of the people-mover at the head of Mount Vernon street. The crosswalk (at the lower traffic circle) would have required protection by a traffic light.

8 - Quality-of-life effects. Because the people-mover was to be electrically powered, and, presumably, quiet in operation (to protect its passengers from noise), we assumed the structure would not cause any local air, water, or noise pollution. However, it might have proven a visual blight on the neighborhood.

9 - Safety. We treated protection from system failure as an engineering and design problem. However, certain considerations of safety entered into routing consideration. Would, for example, a station located far from any frequented area act as a magnet for muggers, rapists, or armed thieves?

10 - Acceptability to the community. In general, this means acceptability to the Columbia Point community, and applied only to routes that would pass within the neighborhood of the project. Stuart Traver conducted an informal poll at Columbia Point, inquiring of persons on the street their feelings about the alternatives we had evolved. Most responded favorably to the one ultimately selected, the elevated structure on Mount Vernon street.

Further, Bruce Schwartz developed a set of design criteria:

* the structure would have to support the belt system and its operating equipment;

* it would have to protect the system and passengers from the elements;

* it would have to be safe and reliable, attractive as possible in terms of comfort and appearance so as to win riders away from competing modes of transportation (primarily the automobile);

* its appearance ought ideally to enhance the environment into which it would intrude--at the very least, it should not degrade it:

* its construction cost would have to be reasonable within the criteria established above, or at the very least, such that the long-term cost of the system would be comparable to or better than that of other (e.g., bus) systems.

The nature of a moving-belt people-mover dictates that whatever form its enclosure takes, it will be some form of a tube. Routing becomes the problem of where to put this tube, which, in the case of the system we were contemplating, would be such as to accommodate a five-foot-wide belt

for each direction of travel, plus ancillary structures such as handrails. Routing the tube in the form of a continuous loop (MBTA to U. Mass. and back) as had been suggested for high-speed rail links did not seem very practical, since it would require rights of way for both directions of travel. We decided, then, to put one "lane" in each direction into the tube of the people-mover. We were now talking about a tube, at minimum, twelve-feet wide. The orientation of this tube could have been handled with any combination of three alternative basic construction types:

Subterranean - system predominantly or entirely underground;

Surface - at grade or below grade, but not buried;

Elevated - in the air, support on pillars of some kind. Two basic elevations were considered; low - permitting pedestrian underpassing, and high - permitting all traffic, including truck, to underpass.

Determining the route

Origin. The destination of the people-mover was, of course, to be the U. Mass. campus. The origin could have been either of two MBTA stations roughly equidistant from the campus: Columbia or Savin Hill. We considered a route that would have run north from Savin Hill station on the MBTA right-of-way, then swung east around the Savin Hill community, crossing Morrissey Boulevard and terminating at the southwest corner of the U. Mass. campus, near the school's motor entrance (currently under construction). This would have eliminated entirely the chance of serving the housing project, and because this was ranked so high in our calculations, we rejected a route from Savin Hill.

Availability of land was such that only three possible routes from Columbia Station to the campus (via the housing project) could be discerned. The first, dubbed the "shore route," would have originated at or near the Columbia station, headed northeasterly across the shopping-center parking lot, skirted the housing project's north side along Dorchester Bay, and eventually swung south toward the campus. A station would be constructed behind the housing project. The "Mount Vernon" route followed Mount Vernon street to just past Monticello Avenue where it broke to the south toward the campus. A third route, dubbed the "inland route" would have originated near the Columbia station and followed a fairly direct route south of the church and elementary-school grounds, but north of B.C. High, to the campus. (See figure 1 page 10)

The alternative support structures had to be considered in the routing selection. Stuart Traver prepared a decision matrix which illustrated the interrelatedness of various factors and the weights to be assigned to each and administered it to the class to determine their preferences. (Nearly all rated the Mount Vernon route highest, primarily because it was a fairly direct route, on land already owned by the city, and located adjacent to the Columbia Point housing project's main entrance. Five preferred under-

ground construction for this route; four rated an elevated structure first choice; two wanted the people-mover built at grade. (We felt that the class had underestimated the expense of underground construction; confronted with the information, the students shifted preference to the elevated system.)

Both the "inland" route and the "shore" route had problems with land availability and acquisition since they traversed property in private hands. The "inland" route had further to its detriment its distance from the housing project, making a convenient station impossible. The "shore" route was the longest of the three. Its placement along the shore of Dorchester Bay, we feared, might have ruined the area for any future development as a recreational area, should the bay eventually be cleaned up and made suitable for swimming. We felt that we could design a system along Mount Vernon street that would not only not degrade the neighborhood but enhance it, and this, coupled with the availability of right of way, swung our consideration toward the Mount Vernon-street route.

Construction on grade presented problems with all three routes we considered. For one thing, we knew that the people-mover should begin as close to the Columbia station as possible. Otherwise, the walk between transfer points would make the MBTA-people-mover interface far less attractive to passengers and might cause them not to use the system. Hence we decided the system would have to begin at the Columbia station and either bridge or underpass Morrissey Boulevard (or the traffic interchange to the north) in some fashion. So immediately, construction at grade was impossible over the entire route.

However, we considered the possibility of overpassing Morrissey Boulevard and then descending to grade. This posed problems on both the shore route (it would cut Almy's parking lot in half and block access to the shore) and on Mount Vernon (it would create a "Chinese wall"). Once we decided upon the Mount Vernon Street route as most direct and the one that best served the housing project, a surface routing became undesirable without modifications to permit extensive pedestrian overpassing. Additionally, it would have either to rise up to permit construction of an elevated station at the project or else to descend into an underground station.

Underground construction alone would eliminate the "Chinese wall" hazard and disruption of traffic patterns; additionally, we would run no risk of creating visual blight by imposing an ugly structure upon Mount Vernon Street. On the other hand, subterranean constructions have certain disadvantages. Psychologically, subway systems tend to embody certain cave-like oppressive qualities unless careful attention is paid to lighting, decor and surveillance. Natural light never penetrates. The impossibility of observation from the street makes subway-platforms cisterns for violent crime--armed robbery and muggings. Clearly, we did not want a system, especially in the high-crime Columbia Point area, that people might be afraid to use.

Engineering problems also intruded in our considerations. The water table at Columbia Point is extremely shallow, about 12 feet below the surface, necessitating sealing and/or sump pumping in a fully buried system. Excavation is relatively costly; moreover, Morrissey Boulevard could not be underpassed by cut-and-cover methods. A major (and overburdened) Boston traffic artery, its disruption by excavation we judged too high a cost. Underpassing would thus require tunneling, and soil conditions in the area would dictate extensive and expensive shoring.

One way of handling this would have been to design a system overpassing Morrissey Boulevard on pylons, then dropping down below street level once on Mount Vernon. This would mean building an elevated structure as far as the Firestone station, at least, in order not to disrupt traffic on Mount Vernon Street by overpassing if we wanted to go down the center of the street. (By going down the south side of the street we could begin dropping much sooner, however--though we would then be faced with ensuring enough clearance for the driveways of the First National Bank.

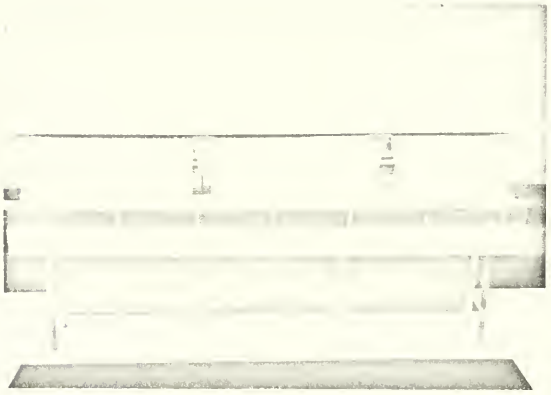
Since the construction was now seen to be one-third elevated anyway, why not make it totally elevated? This would also allow Lance Dickes to design a station on Mount Vernon Street for the local residents that would be more than just a transit stop. The cost of excavation and the possibilities of pre-fab construction of an elevated system, plus the possibility that it could actually be an enhancement to the neighborhood, led us to choose an elevated system. Photograph 1 shows Bruce and Stu's model of the route taken by the people-mover from the MBTA station over to Mt. Vernon St.

Support-structure design

The people-mover support structure is relatively lightweight since the load it must bear (people evenly distributed on a moving-belt system) is small, even relative to the weight of the structure. Hence the support structure has to support only itself, some people, belts, rollers and machinery.

The weight of the structure is borne by pylons embedded in the soil and bonded to a concrete island sufficient to prevent significant settling of the pylons. This island is 14-feet wide where the structure traverses the midline of Mount Vernon Street. The island distributes the structure's weight over a large area and should eliminate the need of deep pile-driving, since the structure is so light and the sandy soil of the area is capable of supporting at least two tons per square foot. Along most of the route, the support structure is a minimized frame of steel I-beams set continuously over a double row of reinforced-concrete columns six-feet apart at their bases and about 4-1/2-feet apart at their juncture with the deck frames. They are angled in for two reasons: stability against sway, and appearance. Where the structure rises to span Morrissey Boulevard, somewhat sturdier pillars will be required. The span across the large parking lot just east of the MBTA station requires that the concrete base for the pylons be set flush with the surface of the lot, so as not to break it up. (See photographs 2 and 3.)

PHOTOGRAPH 1. MODEL OF ROUTE FROM THE COLUMBIA MBTA STATION TO MT. VERNON STREET



PHOTOGRAPH 2. MODEL SHOWING SUPPORT STRUCTURE OF PEOPLE-MOVER

The overall width of the enclosure is 18 feet; its height, 12, giving an overall above-ground height of 27 feet along Mount Vernon Street. It will be sufficiently far from housing-project buildings to preclude "territorial" intrusion into their perceived living spaces.

The concrete island acts as median strip for Mount Vernon Street 14-feet wide, it reduces the street's 66-foot curb-to-curb width to a still-adequate 52 feet (26 on either side, or two lanes each way), and puts three feet of curb between the columns and traffic--enough leeway for most drivers, drag racers possibly excepted.

The under-side of the deck frames is covered with panels of a light rigid material, such as metal sheeting or fiberglass, brightly colored to avoid the gloomy underbelly often generated by elevated structures. The panels should be removable so that access to moving parts beneath the belts can be made from below.

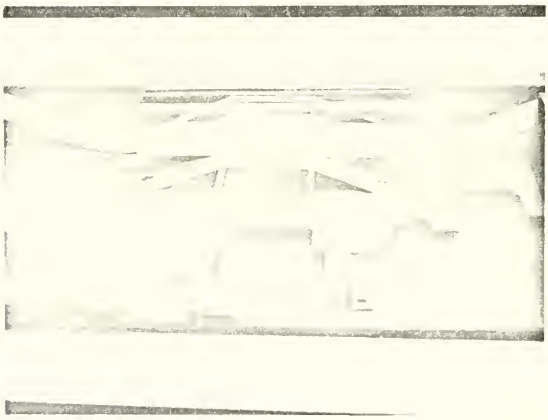
The sidewalls are framed structures covered with, again, a light material, possibly containing insulation in between the "skins"; they are topped by a three-foot strip of safety glass running the length of the people-mover, providing a panoramic view for the passengers and plenty of natural light. The roof is a light framed structure covered with a sheet-metal or fiberglass (or perhaps treated-plywood) sheathing, with periodic glass panels for overhead light and views of the sky. (If the periodic "flashing" to which these panels may expose riders proves disturbing, they may be made opaque.) The roof's exterior is intended to be a bright, colorful addition to the neighborhood environment.

Within the "tube," two belts paralleled by a moving seat and hand-rails carry traffic in opposite directions at a speed projected to be on the order of 10 mph. This introduces the possibility of abrasions to people who fall or scrape against sidewalls. This is dealt with by angling them away from passengers and making these surfaces of corrugated sheet metal that push objects in contact away and reduce surface area in contact. The belts are separated by a medial barrier which also helps to counter the unpleasant feeling some people may get when they are moving, exposed, at 20 mph relative to people coming in the opposite direction. See photograph 3.

The roof is never less than eight feet above the belt. At its peak, it is about 12-feet high, and carries a utility duct for air conditioning and communications lines, for MUZAK, campus radio, announcements, and closed-circuit-TV surveillance by campus police. Signs may also be hung in this central zone. Signs with flashing lights or arrows should be used to designate and warn of approaching exit and entry areas.

(The seat, of course, must terminate well before the end of the belt's run. A gradual shift in the position of the median wall will scrape reluctant sitters off for disembarkation.)

PHOTOGRAPH 3. MODEL SHOWING INTERIOR DESIGN OF PEOPLE-MOVER ENCLOSURE



PHOTOGRAPH 4. MODEL OF STATION DESIGN FOR THE INTERMEDIATE STATION AT THE COLUMBIA POINT COMPLEX

Fireproof construction is called for throughout, and the probability of other disasters (barring mad bombers) should be pretty low. In any event, the structure has the following safety features (in addition to whatever required systems the law may impose).

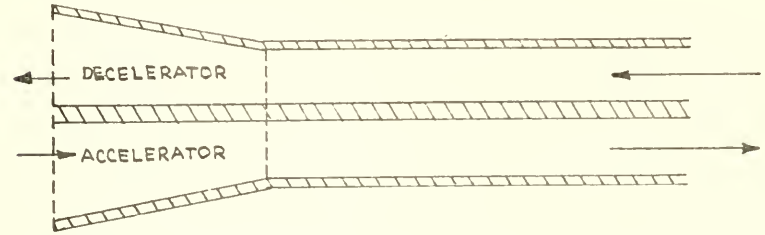
1 - An emergency stopping system, mechanical or electronic, located in the median wall, which can be reached by leaning over the seat.

2 - Emergency windows every hundred feet or so which can be pushed out (like bus windows). Escapees reach the ground by releasing swinging ladders and climbing down.

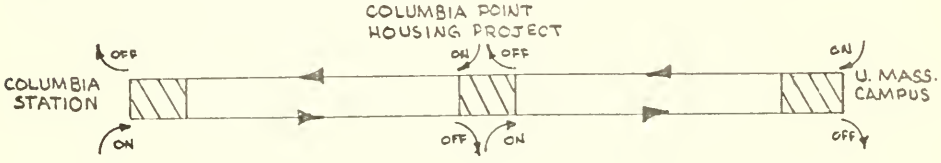
Finally, the outer sidewalls of the people-mover can serve a community function as marquee, bulletin board, or art display. The removable panels can be used for anything from an African-heritage frieze, to "COLUMBIA POINT WELCOMES YOU" in three-foot-high letters. Controlled by a community committee, this people-mover display might confer an exciting and attractive uniqueness upon an otherwise drab neighborhood. After all, what other areas has its own people-mover with frieze?

Designing the interface--Lance Dickes

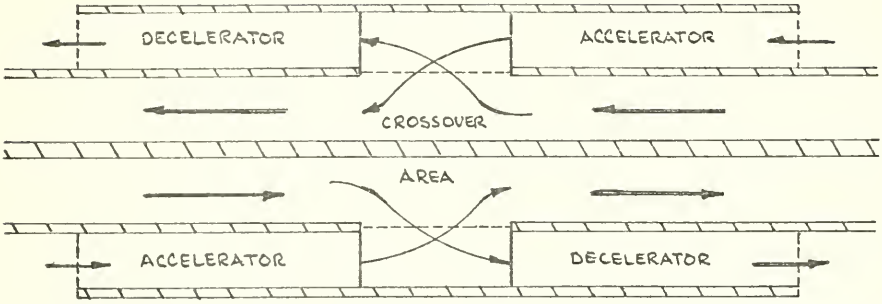
Stations at the MBTA station and at U. Mass. are "end" conditions and therefore can each have an "on-line" accelerator/decelerator. Passenger flow is in just two directions (getting on, getting off). This makes the interface problem relatively simple. At peak hours getting on accelerators could cause bottlenecks; to avoid this the accelerator sections can be wide at the beginning and decrease in width as the speed increases. A similar fanning-out of the decelerator section would remove the possibility of people being squeezed together as the belt-way slows down.



The station at the housing project is more complicated because there are more possible variations for getting on and off.



A proposal to solve this interface problem is as drawn here:



This design presents a possible cross-over problem: people entering and exiting on the same-direction belt must cross paths on the constant-speed section of the accelerator. I designed an alternative system which avoided this problem, but it occupied twice the length of the original proposal. Reconsidering the probable loading conditions at the housing project, I found that there will be heavy use toward the MBTA station and returning from it, and a very light load use from the housing project toward U. Mass. and return. This means that the projected cross-over problem very probably won't develop, making it possible to use the first proposal.

As I worked further on this interface, the accelerator group suggested that the accelerator could be used as escalator (i.e., be a ramp). This possibility was employed to bring the level of the moving belt from fifteen feet to five feet above ground level where the main deck of the station was established. (See photograph 4.)

An acceptable slope for the ramp-accelerator should be determined experimentally. In the model we have suggested some of the ways the deck and the surrounding areas could be designed to allow many possible uses--creating a community focus, e.g., outdoor/indoor meeting places, information center, political-action center, theatre spaces, playground and day-care center. These plans should be further developed as the people-mover continues to evolve. Our feeling is that a system should not be built or planned without an integral development of plans for positively dealing with its extensions and effects, analyzing the possible community uses that are extensions of the change brought about by the people-mover in the environment, and making actual physical plans for a real structure in which those possibilities can be actualized.

Recommendation

Should a people-mover such as the one we have outlined, actually be built, it would be necessary to obtain firmer estimates of construction

costs than the generalized values we have obtained. In its design aspects, the project would have to be designed for proposal, submitted to inspection by both the university and Columbia Point communities, re-designed and engineered for minimal cost within the standards of design felt necessary, and re-evaluated in terms of these criteria, up to the moment of construction.

In retrospect, however, it is clear that any engineered, mechanical solution cannot remedy every part of the transportation and social problems of Columbia Point. We tried to solve the problems of U. Mass. and the housing project with one system, but it is a compromise. U. Mass. requires a fast, high-volume transportation link between the MBTA system and the campus. The Columbia Point housing project really needs a system with greater flexibility, one which will link them not only with the MBTA but also with the shopping center and other resources not available in the immediate vicinity.

The problem can be traced back, as Julian Beinart has said, to the initial decision made years ago to locate the housing project, and, more recently, the university, on this isolated parcel of land, making essential support systems difficult and costly to supply--the result being that the problems are ignored or perennially "studied" while the community must continue to function in a disabled state. A people-mover system offers its designers some opportunity at least to alleviate these problems, and such considerations, we feel, must rank high in their minds.

A MOVING-BELT ACCELERATOR

-Lee D. Giguere, Dennis C. Lynch, and Charles F. Gronauer-

Summary

Moving belts, while efficient people-movers, are at present constrained to moving people at speeds usually only a fraction of walking speed. In order to make a higher-speed moving sidewalk feasible, it must be capable of accelerating passengers from about 1-1/2 or 2 mph up to the belt speed. We have found evidence to support the utility of two types of accelerators: interleaved belts, in which adjoining sections of evenly spaced narrow belts run at incrementally higher speeds; and abutted belts, with passive rollers placed in the remaining gap.

Introduction

If a moving belt is to cover any appreciable distance (i.e., over a few hundred feet) it becomes necessary to operate it at speeds well above walking speed, in order to avoid tedium and to induce people to use it rather than an automobile. The principal technical problem in implementing such a high-speed (i.e., 7- to 10-mph) system is providing a means of acceleration which is safe and comfortable and which requires a minimum amount of concentration and effort on the part of its passengers (no more than is normally required of escalator users).

We chose to explore two systems: interleaved belts and simple abutment of flat belts. (See figure 3.) The interleaved-belt arrangement at first seemed the more promising. It consisted of running a parallel series of fairly narrow belt strips (each about 1/2 to 3/4 inches wide) over pulleys with equal spaces in between to allow a second series to be started near the end, but overlapping the first, and moving at a slightly higher surface speed. The advantage of this system is in eliminating the gap caused by the impossibility of turning the belts around extremely sharp radii at the junctions. The second system, simple abutment, is much easier to construct. Two flat belts are simply placed end to end, with some smaller rollers, either driven or passive, to fill the gaps between them.

Method

We purchased heavy industrial belt with which to construct our prototype. Part of the material was cut up into 3/4"-wide sections on a band-saw, to be used for the interleaved segments. The rest was used unaltered as a section of the flat belt, about 16" wide.

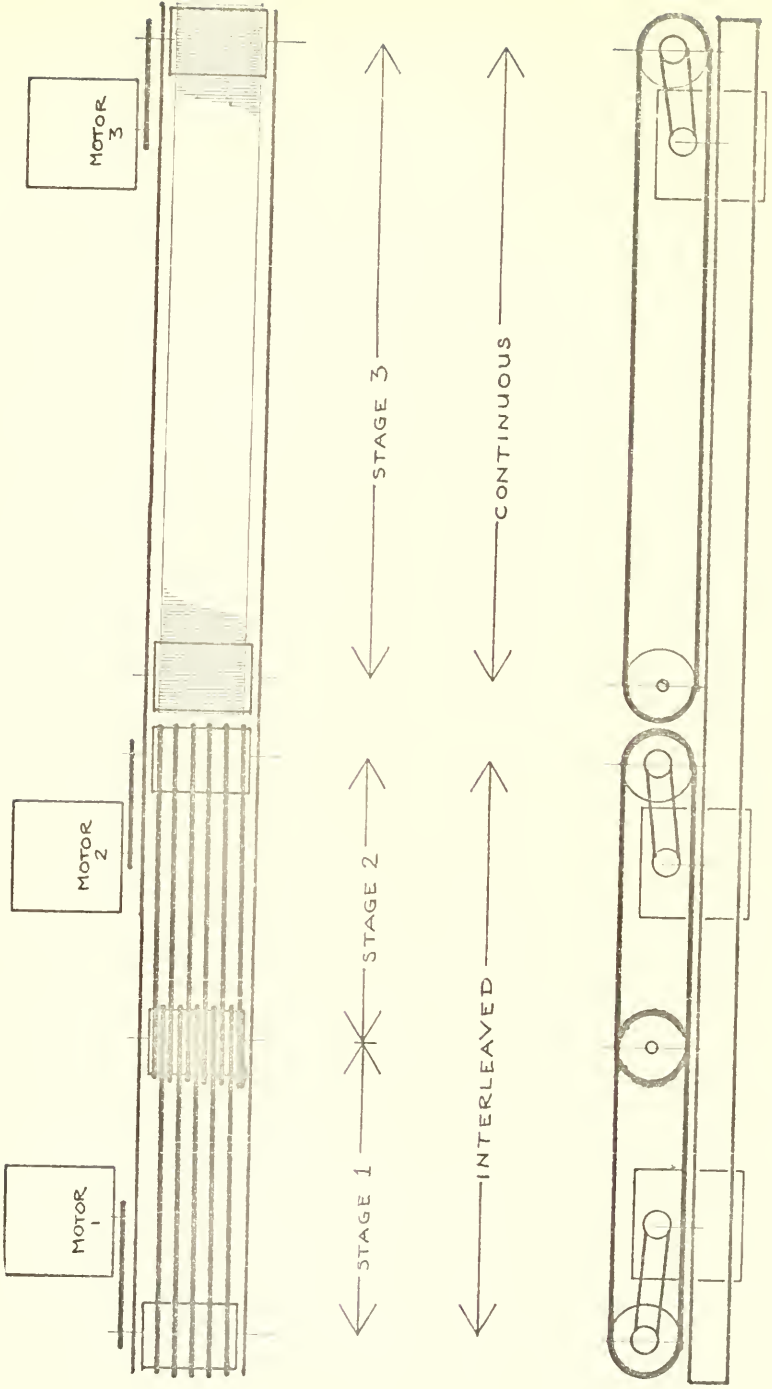


FIGURE 3 ILLUSTRATION OF TEST ACCELERATOR (scale: 1"=2')

We fabricated our end rollers (both drive and idlers) from disks of 3/4" plywood and 1/8" masonite spacers, drilled to fit on a shaft of steel pipe. The plywood and masonite disks were cut from sheets using a fly-cutter and pressed alternately on to the shaft. We hoped that the masonite spacers, which had a slightly larger diameter than the plywood disks, would keep the belts from moving sideways and also would allow for some space between the belts in the sections where they would both be operating. Mounted on the shafts, the disks were turned on a lathe to ensure roundness and concentricity, and were crowned to improve tracking. We pinned every other disk to the drive shaft to keep them from slipping. The center roller, where the two interleaved sections met (see figure 4) was built by using the same type of disks as on the drive rollers, only with slightly larger holes for a looser fit. In assembly these disks and spacers were greased liberally to allow independent rotation and were held in place with set blocks. The idler shaft for the solid belt was constructed out of the plywood disks only and was smoothed out on the lathe. A commercial drive roller was purchased for the flat section of belt. All drive rollers were supported by industrial pillow blocks.

At first, we had considered using hardwood dowels to support the belts along their length. This would allow us, we thought, to turn slots in the rollers for the interleaved sections to keep the narrow belts from slipping laterally. We discovered, however, that bearings for that number of rollers would be difficult to build or obtain, and decided instead to use standard industrial conveyor rollers. We decided to test such an arrangement first, and, if it were found unsatisfactory, to provide lateral support by some other means, such as slotted strips of wood.

All of this was mounted on a frame of 2 x 6's set on edge and nailed to 2 x 4 ties (see figure 5). The support rollers were mounted on Dexion strips attached to the tops of the 2 x 6's. Three variable-speed drives were used to power the system. (See following report on motor drives.)

Conclusions

After some brief tests, we feel that both types of accelerator provide feasible solutions. Even on a narrow belt (16") such as ours, a rider is able to maintain his balance across the junction without lifting his feet and without a hand rail, which certainly would have improved the rider's balance.

We found that we still had some difficulty in keeping the narrow belts tracking properly in spite of the masonite spacers and the crowned plywood disks. (The large belt, riding on crowned roller, tracked very well.) The narrow belts also tended to slip on their drive rollers when loaded. Possibly a larger drive roller would solve the problem by increasing the amount of frictional surface between the belt and roller.

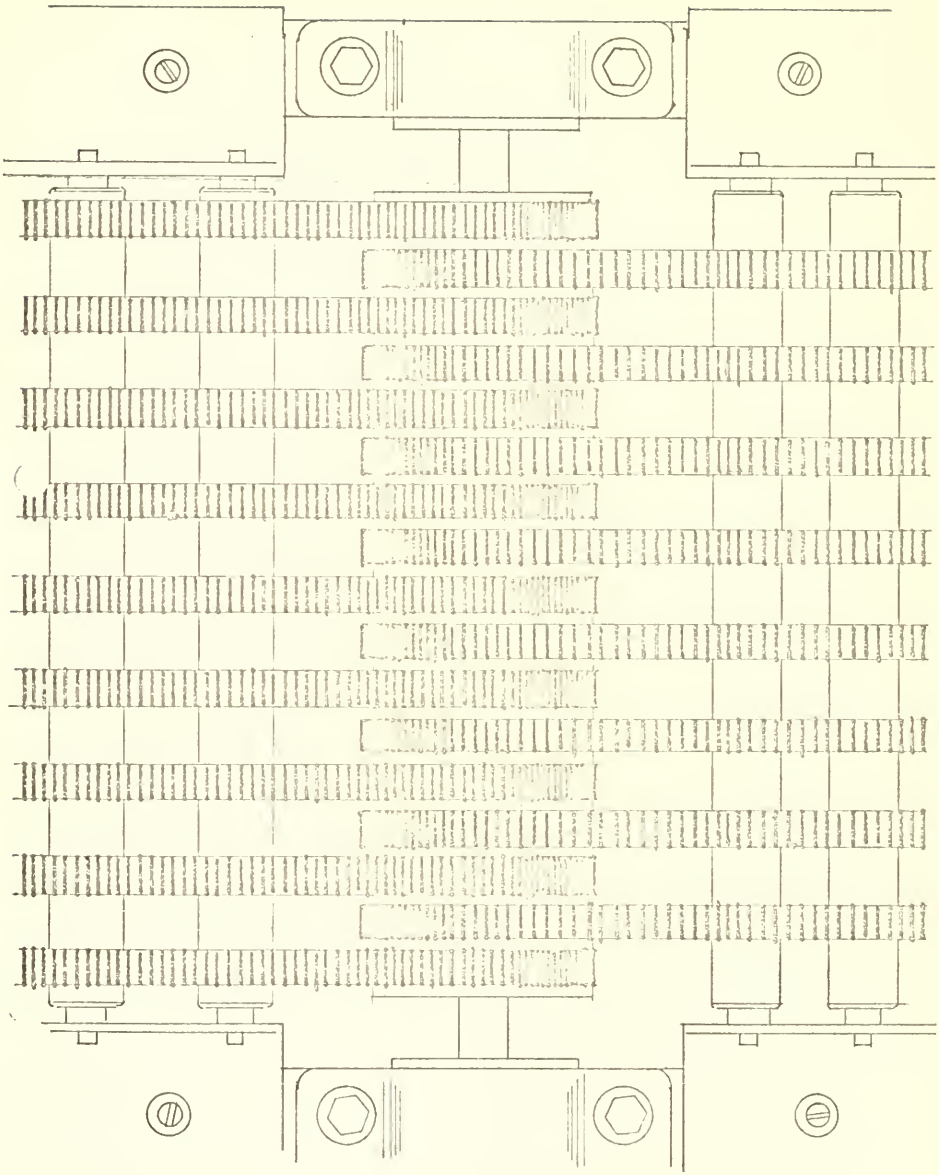
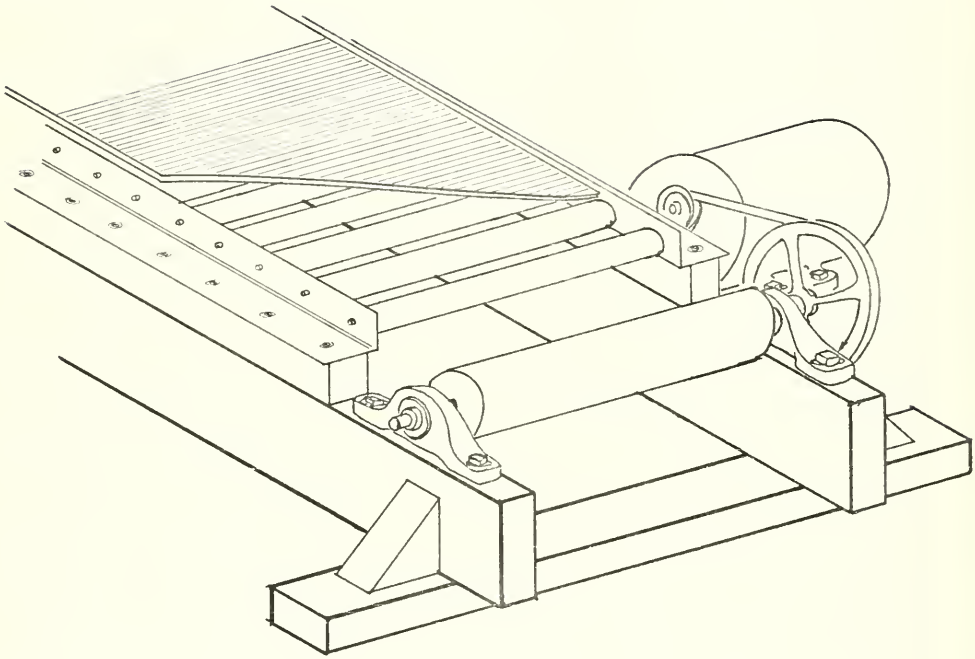


FIGURE 4 DETAIL OF "INTERLEAVED" PART OF ACCELERATOR (scale: 1"=$2\frac{2}{3}$")
(taken at double idler rollers)

FIGURE 5 DETAIL OF SOLID BELT AT DRIVEN END (scale: 1" = 8")



While our prototype seems to have had some faults, we feel that these were largely due to the limitations of our construction, and not to anything inherent in the concept of moving-belt accelerators. Improved crowning techniques and possibly larger spacers should help solve the tracking problem. An idler pulley could be arranged in the system to maintain the required tension in the belts, and possibly some type of material could be bonded to the drive roller or the belt to improve the driving efficiency.

Recommendations

In an actual working system, we feel that the lengths of the interleaved accelerator sections should be adjusted so that a person is on each section for about the same amount of time. In other words, the faster sections should be longer than the slower sections to give the passenger time to adjust to his new speed before being subjected to another step in velocity. (See figure 6.)

The belt, of course, should be made wider than 16". A belt moving at a speed of 10 mph, carrying a single file of people, spaced three-feet apart, has a capacity of 17,600 people per hour. This means that the main belt can easily be as little as three-feet wide (though this is not felt to be an optimal width). It is important to emphasize, however, that the real capacity of the system is determined by the slowest section of the belt. Starting with a 2-mph section, this provides a single-file capacity of only 3,520 people per hour. This suggests that a working system should have a funnel-like accelerator, as suggested by Turner[3], which would start several times wider than the main section so as to maintain a nearly constant rate of flow of pavement area. (See figure 6.) Correspondingly, a fan-like decelerator section would be necessary to prevent a potentially dangerous pileup of passengers at the end of the line during peak flow.

Faculty comment--David Wilson

After the above reports had been made, the interleaved-belt accelerator in three sections was tested over a range of speeds by students, faculty, and by visitors to the course presentation. Even though, for reasons of cost, a constant-width narrow accelerator without handrails was used, and even though there was no decelerator following the accelerator, so that people were ejected rather in the manner of circus clowns out of a cannon, no one appeared to have any difficulty. In particular, the rather sudden changes in velocity from one belt to another did not seem to cause any undue problem. We felt, therefore, that an interleaved-belt accelerator would be a viable option so long as people with pointed heels could be excluded. This provision would be so difficult to enforce that this faculty member, at least, would favor the abutted-belt system. The

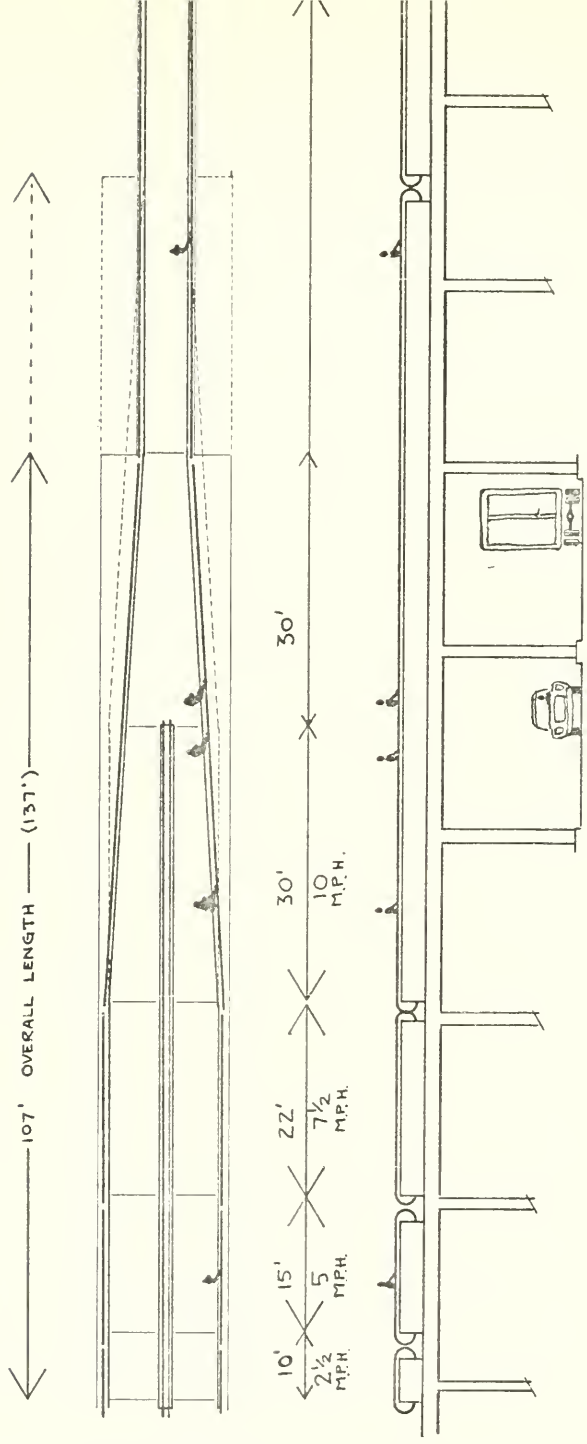


FIGURE 6 PROPOSED DESIGN OF FULL-SIZE ACCELERATOR (scale: 1"=16')

smooth accelerations and absence of slots or steps in the various forms of "integrators" being developed by Battelle, Dunlop, and others (ref. 3) would of course be preferable.

MOTOR DRIVE FOR PEOPLE-MOVER

-Danny S. Caufield-

Summary

The drive system for the moving-belt people-mover will be one or more electric motors. The most difficult part of the system to propel will probably be the accelerator section. Conventional techniques are readily available for application to the high-speed section.

Introduction

The motor drive for the moving-belt system should be electric. There are some safety precautions which must be considered in the design of the motor drive. The installation of an overrunning clutch on each motor would allow the shaft to continue to rotate should the motor seize or fail. Considering the possible safety hazard on the accelerator section, as well as on the main belt, due to motor failure, it may also be advisable to build some sort of redundancy into the drive system, such that back-up motors could carry the load of the system for a small amount of time in the event of a primary motor failure.

No effort was made to study or build a drive for the main high-speed section of the belt. Appropriate techniques are readily available and have been in use for many years.

Prototype construction

Three variable-speed motors were used to drive the test section of the accelerator built for the project. For simplicity, the first section of the interleaved belts was driven at the leading roller (point A in figure 7). Ideally, to maintain the desired tension in the

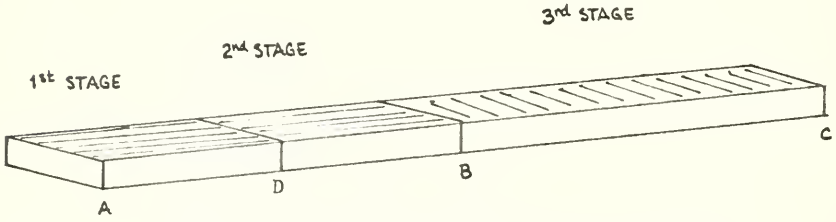


FIGURE 7 THREE STAGES OF PROTOTYPE ACCELERATOR

belts, it should have been driven at point D. But this would have involved keying every other one of the pulleys at D to the shaft, while the other pulleys turned freely on the shaft. The second motor, located at point B, pulled its section of belts at 5 mph, twice the speed of the first section. And finally the third motor drove the solid flat belt at about 7-1/2 mph from position C.

For the prototype system the motors were merely mounted on a Dexion frame adjacent to the platform of the belt and drove the shafts through v-belts and pulleys. (See figure 8.) A belt drive is probably

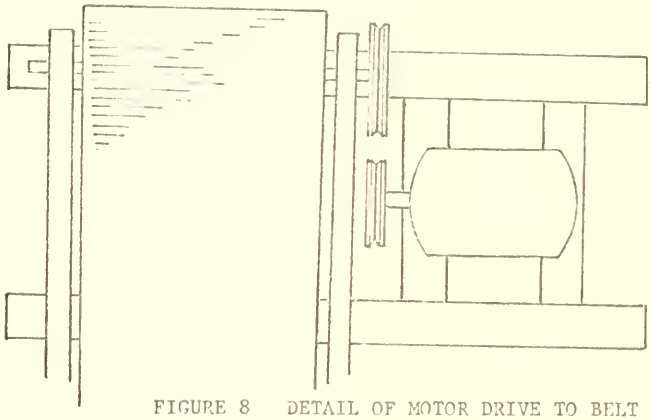


FIGURE 8 DETAIL OF MOTOR DRIVE TO BELT

the most reasonable since the noise created by a chain drive might be disturbing to the passengers and direct drive would require rigidity of the belt and motor frame.

Conclusions

An electric motor drive for the belt system seems feasible and functioned satisfactorily on the prototype accelerator. The most challenging aspect of the problem will be to design redundancy and safety into the system.

HUMAN DETERMINANTS OF SUPPORT ROLLER DESIGN

-A. L. Dias Carneiro-

Summary

This report is concerned with evaluating and measuring the three variables associated with support rollers: their diameter, interspacing, and height difference in an inclined belt path.

Introduction

For optimal comfort and the best support, the belt should ride on a flat surface, e.g., a highly polished metal or hardwood sheet with an anti-friction cover such as silicone. However, due to economic infeasibility (at least in this project and possibly in the full-scale system) a more orthodox roller-support system was examined. In particular the effects of the three roller variables--diameter, interspacing, and inclination--were studied.

I designed twelve support brackets as shown in figure 9 which could easily and quickly be fastened to any of the 2 x 6 wooden beams

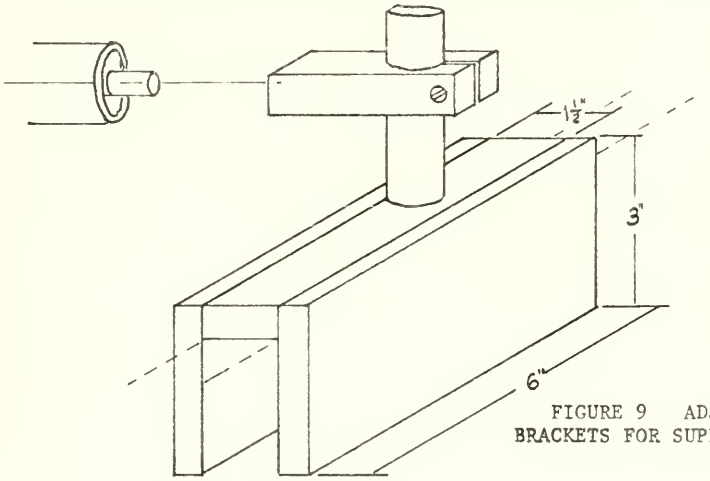


FIGURE 9 ADJUSTABLE BRACKETS FOR SUPPORT ROLLERS

on the base of the belt. These brackets allowed for quickly changing roller diameter, spacing, and vertical displacement. For rigidity the bases of the brackets were built 6-inches long and thus constrained the minimum roller spacing to that distance. However, the brackets gave good results in the testing stage, and allowed me to discover that roller diameter affects comfort significantly only at large separations between rollers.

I concluded in the early part of the experiment that the determining factor for human comfort was minimizing the drop d of the belt between rollers. (See figure10.) This dip causes the belt to

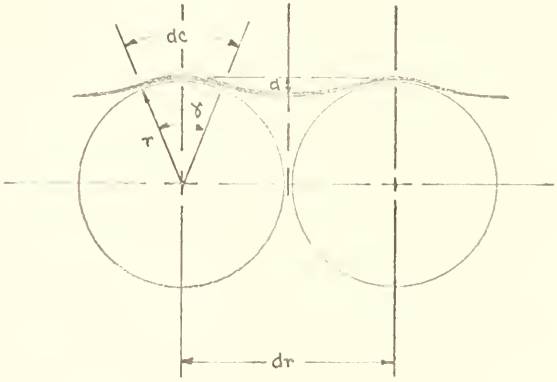


FIGURE 10 BELT DROOP BETWEEN ROLLERS AT MINIMUM SPACING

follow the curvature of the roller for a distance d_c, which I wanted to minimize.

Clearly, for a given roller radius r, we get minimum d_c if we space the rollers by 2r plus a running clearance. Therefore, one will note in figure 2 that

$$d_r \simeq 2r \qquad \text{and,}$$

$$\min d_c \rightarrow \min \gamma,$$

where γ is a function of the weight of the passenger, belt tension, T, rigidity, Y, and roller radius. Therefore,

$$\gamma = \gamma\ (W,T,Y,r)$$

And we find that as

W increases, γ increases
T increases, γ decreases
Y increases, γ decreases
r increases, γ increases

An increasing roller radius gives a profile which becomes close to a straight line, i.e., a flatter support. However, inter-roller spacing is clearly limited by roller radius, and the trade off for increasing radius is a larger belt drop between rollers as well as increased size and weight of the supporting structure. Since it is the up-down fluctuating motion that causes the most human discomfort, I neglected any further interest in large-radii rollers.

Conclusions

High heels of less than one-inch length should probably not be allowed on the system with this type of support structure.* Therefore, I concluded that spacing be limited to no more than one inch, with rollers of approximately that diameter (running clearance between rollers is necessary, of course). At diameters of less than one inch, with rollers as close as possible the diameter should be determined within the following constraints.

1 - The roller has to be above the diameter that a roller can be engineered with suitable strength, durability, and friction characteristics.

2 - The excitation of the natural up-down frequencies of the human body must be avoided.

The maximum incline I was able to achieve safely at belt speeds of 1 to 2.5 mph was 15°. Spacing and diameter characteristics apply here, too, and can be the same as those outlined above. I propose that:

1 - Inclines be made as gentle as possible, with a maximum of 15° for the slower belts and no more than about 10° for faster belts.**

2 - There should be no inclines within a certain distance of drive or idler rollers. A person should travel for at least 0.5 sec. (slow human reaction time) on a flat section between an incline and one of these rollers.

---

* At this point, thin high heels are not allowed on airplanes in the U.S., because they may damage the honeycomb aluminum flooring.

** Current U.S. safety codes limit the angle of inclination of moving belts as a function of their speed.[6]

ESTIMATES OF BELT WEAR

-Wesley H. Henderson-

Summary

It seemed desirable, in designing a moving-belt people-mover, to make some determination of the wear characteristics of the belt and guiding system. Wear tests performed on the belt material could give some clue to the primary life of the system, perhaps altering initial designs.

Introduction

A simple apparatus was built which, it was hoped, would give us a first-order approximation of the wear characteristics of a belt material sliding on a guide. An A.C. electric motor drove a 44-inch V-belt between two 4-inch pulleys. A metal slider, hung from a Dexion gallows, was made to drag on the top side of the belt with a variable force dependent on the amount of weight applied (see figure 11).

Tests

Two wear tests were run, one of six hours and the other of 24 hours, both at 3.5 mph. Assuming the percentage of mass loss which would demand replacement of the belt was approximately 30%. The first test, six-hours long, gave a belt life of 40 non-stop operating days, and the second test implied a belt life of 81 days. In table form, these tests gave the following results:

		before	after	loss	% of total weight
1st test	weight of belt	107.7g	107.5g	+0.2	0.18% loss
6 hours	weight of guide	84.9g	85.0g	-0.1	0.11% gain
2nd test	weight of belt	107.5g	107.1g	+0.4	0.37% loss
24 hours	weight of guide	85.0g	85.2g	-0.21	0.30% gain

The distance covered by the 6-hour test was 21 miles, while the 24-hour test ran 84 miles.

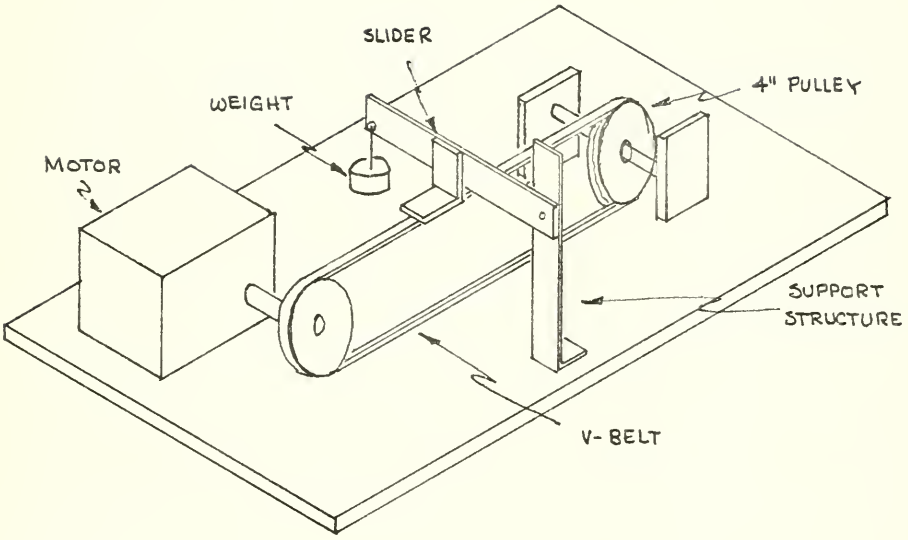


FIGURE 11 DIAGRAM OF TEST APPARATUS FOR MEASURING BELT WEAR

Conclusions

Under extremely severe abrasion, which would normally not be allowed in any part of the system, the belts tested showed an excessive wear rate, but even so considerable operating time was given. More realistic tests are needed in which the life of the belt under only moderate scuffing but under repeated bending conditions needs to be assessed.

EXPANDING-LINKAGE DRIVE SYSTEM

-Dave F. Swoboda-

Summary

Since the moving belt and its passengers are to be accelerated from about 2 mph to about 10 mph, the objective of providing a place to grip continuously throughout the acceleration becomes much more complicated than simply providing a constant-speed handrail. Since there are long parts of the people-mover traveling at constant speed, an escalator-type handrail would probably be sufficient for these portions. A mechanically-expanding handrail was designed, and a prototype built and tested, which appears to be a very promising solution for the variable-speed sections of the people-mover system.

Introduction

Since the stabilizing effects of a handrail on the people-mover are most critical during the process of acceleration, and since the technology required for a constant-speed hand grip is presently readily available, the main thrust of this effort was to provide a rail with a variable speed which would parallel the acceleration of the moving-belt. It should also, however, be compatible with and adaptable to the constant-speed sections.

It would seem that for efficiency and simplicity, a handrail should work on the same principle as the belt drive so that the two systems could be driven together and avoid redundancy. Unfortunately, the interleaved belt does not seem to be adaptable as a handrail system. I could not think of a simple similar system in which people's hands would not be caught between belts and pulleys.

Consideration of a horizontal railing which would be continuous raised a basic geometric problem. When the handrail accelerates, points along its length become farther apart, so that the system must be able to expand along its length. If it were a solid material (such as rubber) it would thus lose cross-sectional area. It might also be telescoping or unfold in an accordion-type arrangement. The problem with these last two schemes is that during deceleration, a person's hand could very easily be pinched.

Since at any section of the belt a person would only grip one small part, all that is really needed are parts of a rail spaced evenly. This would also tend to space the passengers more evenly. Thus a system with discrete hand grips in the form of short horizontal or vertical poles, or a seat on wheels (figures 13 and 14), was seen as both a satisfactory and desirable scheme. The pole spacing would be of major concern so as to prevent pinching or congestion during deceleration.

Figure 12 shows the geometric principle of the link system, which expands or contracts horizontally depending on the width of the track. Where the track is wide, the links will constantly move at a slow speed (1-1/2 to 2-1/2 mph). As the track narrows, the linkage will expand laterally, and points on it will accelerate until they reach the constant high-speed section where the track is narrowest. Deceleration would, of course, be the reverse of this process.

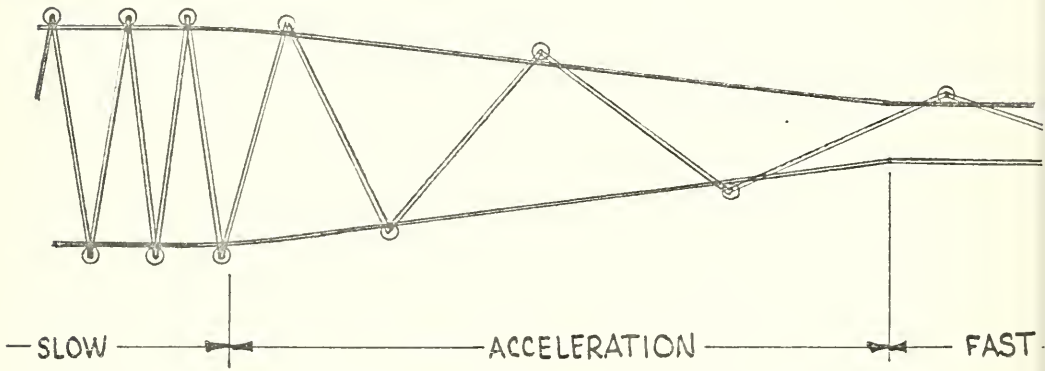


FIGURE 12 DIAGRAM OF EXPANDING-LINKAGE DRIVE

Model construction

Originally I considered a solid-link system which would hinge only near the axles of the wheels. The linkage could be either pushed or pulled through its track so that the wheels rode on the outside or the inside of the track respectively. A test of an original prototype system of five aluminum links, five axles, and ten (roller-skate) wheels showed that it rolled much easier in tension than in compression and showed remarkably little tendency to jam in the tension mode. With these results it seemed that a much simpler system could be arranged if it were always run in tension. Then the links would need to be hefty enough only to take the tensile loads, and only the inside portion of the track would be necessary.

One of the most important considerations was the question of how tightly the system could turn a corner. Using solid links with an acceptable amount of slop at the joints, the linkage could make large curves, such as might be encountered in the middle of the route, with relative ease. However, the real problem would be encountered at the end of the system where a 180° turn is required, since the whole system is of neces-

sity a loop (see figure 15). As the links were originally put together, they were capable of turning in a radius of not less than 140 inches. When they were loosened up the turning radius could be reduced to about 33 inches which was not too unreasonable, but the slop in the system was objectionable. At the expense of added cost and complexitv, hinges could be added to some or all of the links to allow for turning, while reducing excess play at the joints.

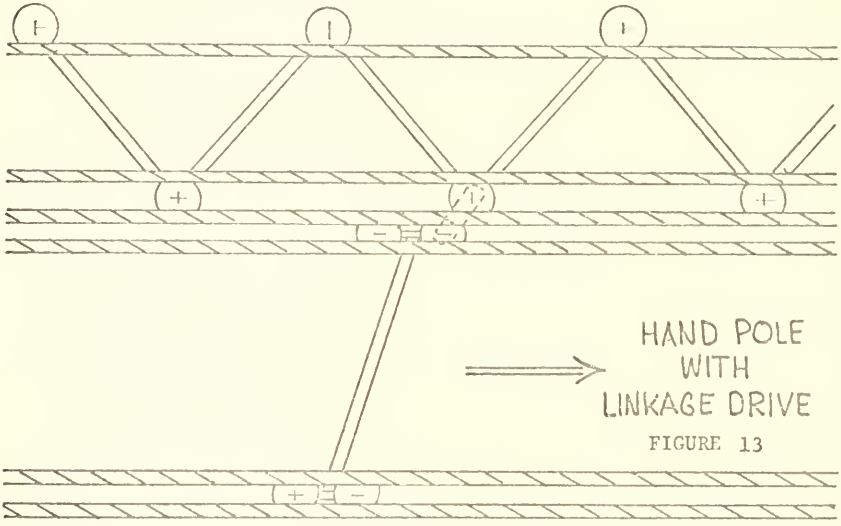


FIGURE 13

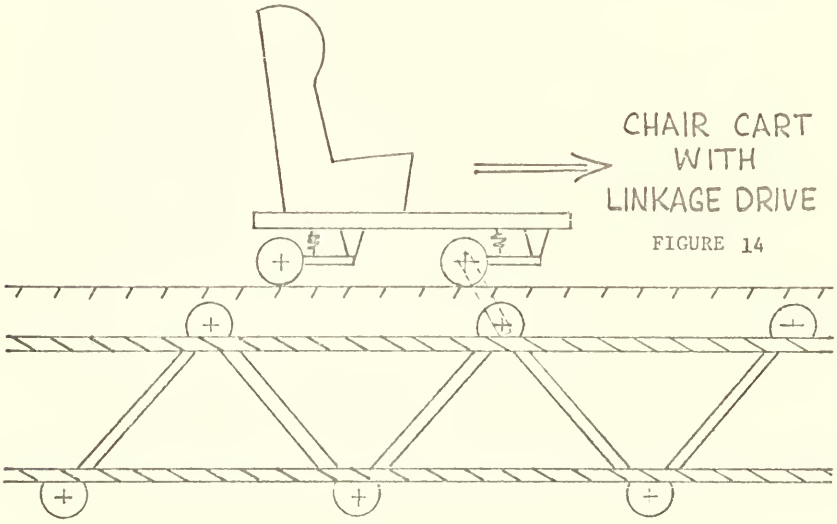
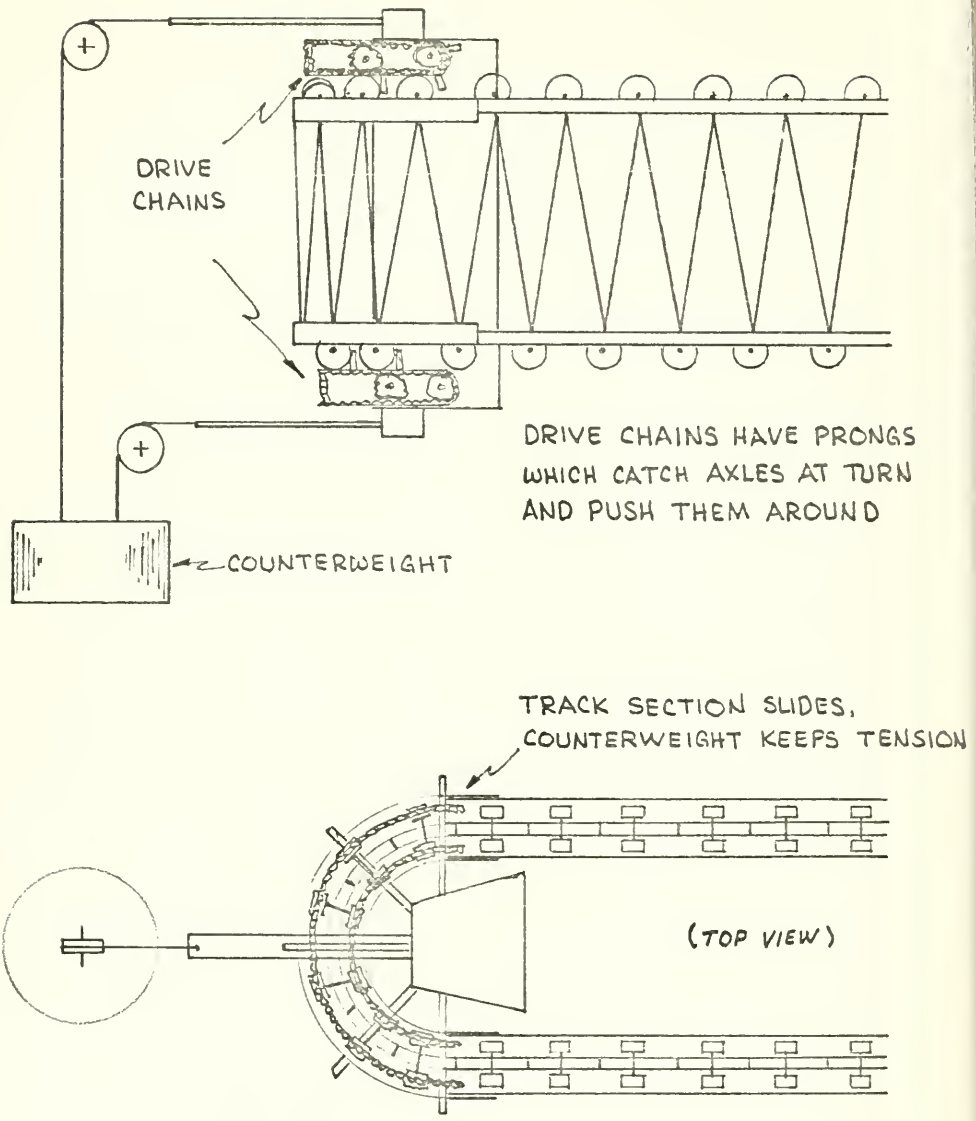


FIGURE 14


DRIVE CHAINS
DRIVE CHAINS HAVE PRONGS WHICH CATCH AXLES AT TURN AND PUSH THEM AROUND
COUNTERWEIGHT
TRACK SECTION SLIDES, COUNTERWEIGHT KEEPS TENSION
(TOP VIEW)

POSSIBLE SYSTEM FOR MAKING A 180° TURN

FIGURE 15

By using cables as the link between axles, almost any radius could be turned, and the system would be considerably simplified. No looseness of linkage and complicated hinge system would be necessary. The track would need to be only on the inside and the wheels would continuously ride on one surface, instead of jumping between two, changing direction of rotation each time.

Testing

In order to run tests on system performance a longer and smoother track was made using cables for links and steel channels for wheel guides, with Dexion as the supporting structure. (See figure 16.) The test section was adjusted for various amounts of expansion by raising or lowering the top track, keeping it parallel to the bottom track. The spring scale was set with a riding needle which recorded the highest force applied to it for any single run. First, a series of weights were attached to the scale by a cable running over the pulley on the end of the track. The static load was thus measured as the force applied to the spring of the scale. This accounted for any friction in the pulley or inaccuracies in the scale. For testing, the linkage was inserted between the pulley and the scale, and the cable was pulled by hand over the pulley. Thus the additional force measured on the scale could be considered as due to friction in the linkage. Many tests were run with various loads and link angles.

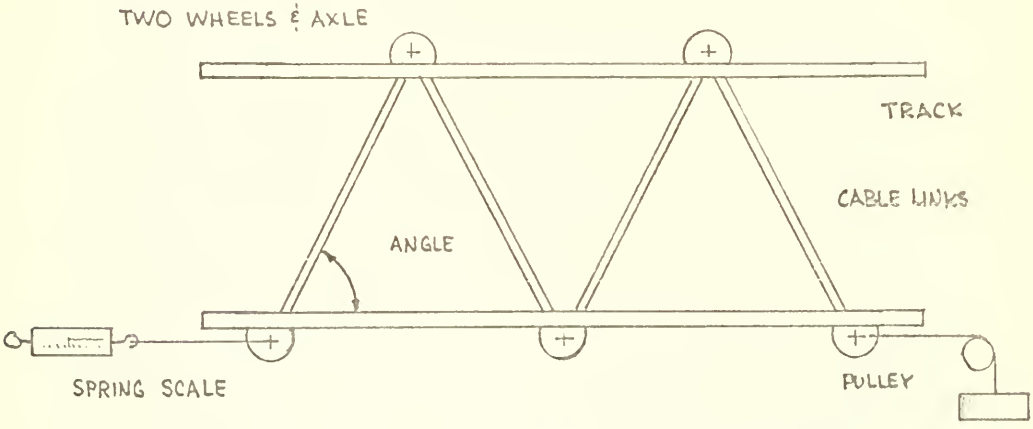


FIGURE 16 FRICTION TEST APPARATUS

A few tests were then run to measure the frictional forces due to the vertical load on an axle. (See figure 17.) The static frictional forces were recorded as those necessary to move the wheel from a standstill. The tests were done with one of the wheels rubbing the flange of the channel, since this would be the position that would cause the most resistance. Fig. 17 shows the results, which should be considered as a rough approximation.

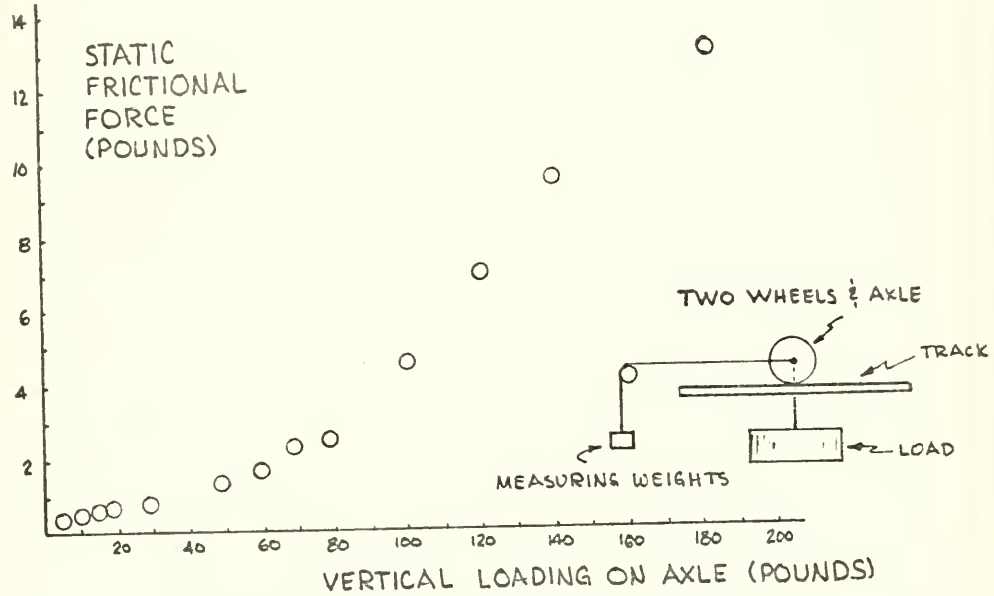


FIGURE 17 RESULTS OF FRICTION TESTS ON LINKAGE

From this information, frictional forces in the system could be calculated and compared with the results actually obtained in tests on the system. The vertical load on any axle will be related to the horizontal load the system must pull by the angle which the cable makes with the track. As this angle is increased, the vertical load on the axle is increased to be compatible with the same horizontal pull. The tangent of the angle multiplied by the horizontal load will give an F_v, which would be the vertical loading on the axle due to a single inclined cable. The five-link system was made of three axles with two inclined cables each and two axles with one cable each. Thus there were three axles with $2F_v$ as the force. The expected total friction can be approximated from the graph.

Conclusion

The calculated static friction is always much higher than the recorded static friction. This probably indicates that the axles line up fairly well when the system is in tension, and the resistance from the sides of the track is not important. It is assumed that most of the retarding force in the system, once it is moving, will be in rolling friction of the wheels, though this particular quantity was never actually measured in the experiments. The system would probably require drives very frequently on the slow constant-speed section, but not so often on the high constant-speed section. No drive would be necessary on accelerating and decelerating sections.

The system of mechanically expanding linkages appears definitely feasible as a basis for a handrail for the accelerator of the people-mover, but probably not for covering speed ratios of over 6:1. With lighter loads a greater range of speed is possible since, by geometry, most of the speed range is during the compressed state where the loads are consequently larger.

Faculty comment--David Wilson

Dave Swoboda's nice arrangement for smooth acceleration of the handrail offers the additional possibility of accelerating a chair or other vehicle, probably in several stages. In other words, one might well dispense with the moving sidewalk.

TOLERANCE TO DECELERATION ON A MOVING BELT

-Seth E. Cohen and Joan S. Bender-

Summary

In preparation for the design and construction of a moving-belt people-mover, much information is needed concerning human reactions to various speeds, accelerations, decelerations, etc. The purpose of our experiments was to discover what accelerations and/or decelerations were satisfactory, comfortable, and tolerable. Two sets of experiments were performed: the first tested human reaction to step changes in velocity and the second tested reactions to gradual velocity changes.

EXPERIMENT 1

Introduction

Our first approach considered how large a change in velocity a person can comfortably tolerate at one time. Deceleration would not be steady, but would theoretically be infinite and would last for an infinitely short period of time. This is illustrated in the graph below:

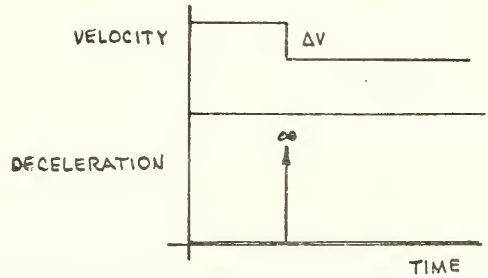


FIGURE 18 DECELERATION FOR STEP CHANGE IN VELOCITY

In practice, we could not provide quite so fast a step change. The duration of the deceleration was approximately one tenth of a second, a short enough time that this could be considered a step change. This type of velocity change would apply to a moving-belt system in which the passenger passes from a belt traveling at v_1 to a belt moving at v_2, where these two velocities would differ by a discrete amount. An example of such a system is the following:

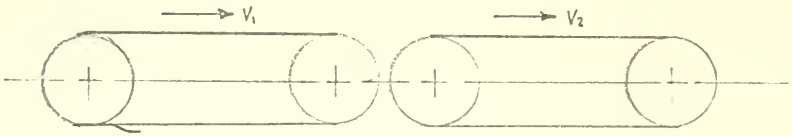


FIGURE 19 SIDEVIEW OF BELTS AND ROLLERS

It is also exemplified by the system illustrated below, where the passenger is accelerated in one direction (→) by stepping in a perpendicular direction (↑) on to parallel plates moving at successively higher speeds:

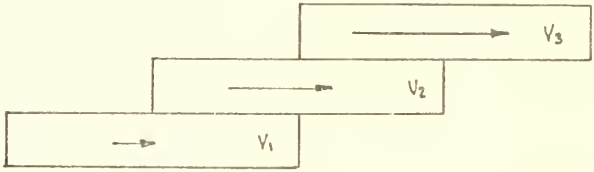


FIGURE 20 MOTION ON A PARALLEL-PLATE ACCELERATOR

To obtain the data we required, the experiment setup had to:

1 - provide a step change in velocity;

2 - measure the instantaneous velocities, v_1 (initial) and v_2 (final); and

3 - measure the human reaction.

The method chosen to satisfy condition 1 was to collide a cart, carrying the subject at a constant velocity, v_1, into a slightly padded barrier to produce an essentially infinite deceleration. Two basic assumptions were made concerning the validity of the experimental data.

1 - On a moving belt a change in velocity from zero mph to v_1 is equivalent, in human effect, to a change from v_1 to $2v_1$.

2 - Due to the difference between falling backward and falling forward, deceleration may be slightly more tolerable than an equal acceleration. We used only deceleration in our tests, and therefore suggest that the results be modified to a small degree if applied to acceleration.

We at first attempted to satisfy condition 2 by having a person walk along the hand-pushed cart, marking the wall at equal time intervals. We found this to be too difficult to coordinate and settled for a rough determination of impact velocity v_1. We timed, instead, how long it took to travel the last six feet before impact. The velocity during these last

six feet was very close to being constant, so our results were not too adversely affected by this method of measuring. The final velocity, v_2, was always zero.

Finally, meeting condition 3 required a subjective approach. To measure reactions quantitatively, such as by variance in heartbeat with foot pressure, would have been quite complex. Also, we would have had to read what these quantitative results meant in terms of human comfort, a rather arbitrary assignment. In our qualitative scheme we asked the subject to evaluate his experience on a scale of one to three:

1 - quite comfortable, little adjustment needed;

2 - acceptable, some adjustment needed; or

3 - unacceptable.

The subject was asked to keep his eyes open so that he would be somewhat prepared for the impact, but he was not to brace himself. Five people were tested, and each experienced both a large step change (2 or 3 feet per second to zero) and a small step change (1 or 2 feet per second to zero). Preliminary runnings of the experiment gave us a feeling for clearly unacceptable step changes, and obviously acceptable changes.

Conclusions

The "psychological effect" is plotted below versus change in velocity:

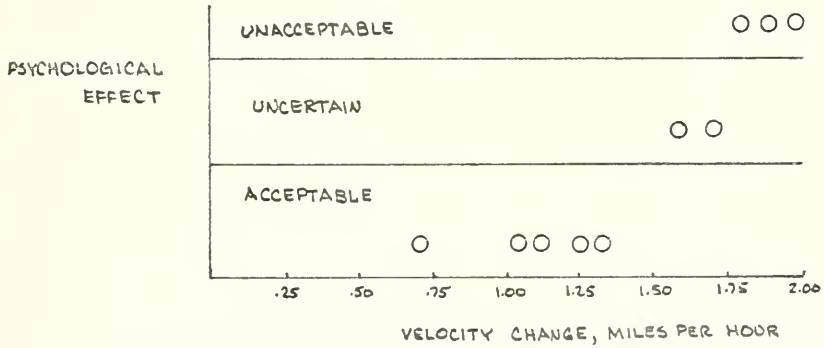


FIGURE 21 ACCEPTABILITY TESTS FOR STEP CHANGES IN ACCELERATION

We felt able to conclude that, in a situation where the user is aware that he is to be decelerated, and the deceleration is virtually instantaneous, that 1.5 mph is an absolute maximum step change, and that 1.2 mph is a more reasonable value.

EXPERIMENT 2

Introduction

After completing the first experiment we decided to do experiments that would involve constant acceleration or deceleration. This seemed more applicable to a system of interleaved belts, such as were designed as the mode of acceleration for our people-mover. Since the interleaved belts overlap for an arbitrary distance, the person's velocity does not jump sharply from v_1 to v_2, but rather is some combination of these two velocities in the overlap region. Thus it seems the velocity transition would be gradual and perhaps linear, though tests should be carried out to determine if this is really so.

We wanted to determine what constant acceleration would be comfortable. These results would be important in determining the length of the accelerator section of the belt.

Again we chose to test deceleration rather than acceleration. The design of the experiment had three requirements:

1 - a way to provide constant deceleration,

2 - a way to measure acceleration and velocity very accurately throughout the critical phases of the experiment, and

3 - a way to measure human reaction.

A constant braking force was applied through a friction apparatus as shown in figure 22. A metal tape was made to slide beneath five slats of

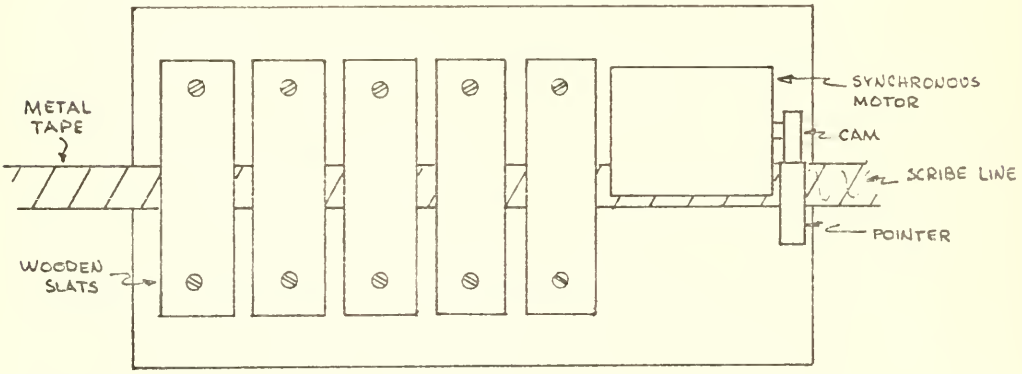


FIGURE 22 TEST-VEHICLE-BRAKING MECHANISM

wood which could be individually screwed down to any pressure to apply frictional braking force on the tape. One end of the tape was attached to the back of the cart carrying the passenger and the other was wound around a supply reel.

During the experiment, the cart and its passengers were accelerated up to a constant velocity by a human pusher. At a preset point the pushing force was removed, and the braking force gradually brought the cart to a stop. The subject was then asked to evaluate his experience as acceptable or unacceptable.

Measurement of the deceleration was accomplished by scribing points on the metal tape at regular time intervals. The scheme used is shown in figure 23. An offset cylinder, or cam, was fitted onto the output shaft of

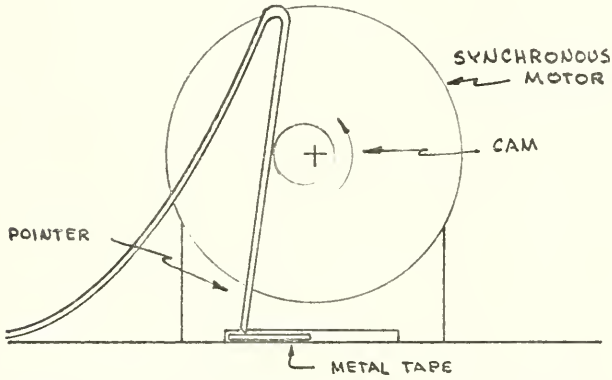


FIGURE 23 APPARATUS FOR SCRIBING TIMING MARKS ON TAPE

a synchronous motor rotating at 1800 rpm. As the cam rotated it alternately pushed and released a piece of springy metal tape, filed to a point at the free end. The pointer left a series of sine-wave-like scratches on the painted metal tape as the cart was pushed, released, and came to a stop. Because the motion of the motor and pointer was periodic, we could determine both the velocity and deceleration of the cart:

$$\text{velocity} = \frac{\text{distance between two peaks}}{1/30 \text{ second}}$$

deceleration = change in velocity/change in time

Figure 24 is a side view of the entire system in operation.

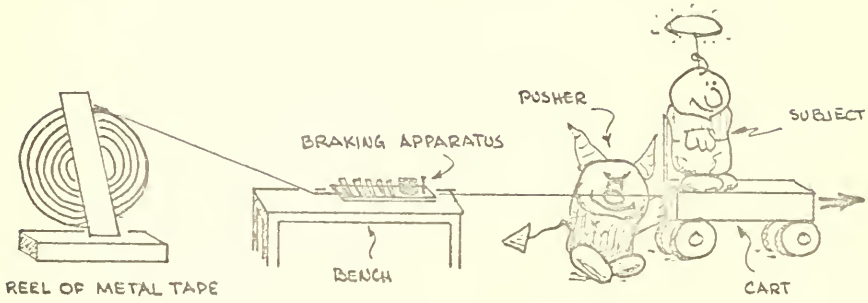


FIGURE 24 DECELERATION-TEST APPARATUS

The degree of acceptableness or unacceptableness of the deceleration, Y_o, is, in general, a function of two experimentally determined values:

$a_o \equiv$ the constant deceleration, and

$t_o \equiv$ the total time of deceleration.

The acceleration was assumed to be a constant during the braking process. If for some reason the data failed to comply with this premise, the approximation was made that

$$a_o = \text{constant} = a_{max} - \frac{1}{3}(a_{max} - a_{min}) = \frac{2}{3} a_{max} - \frac{1}{3} a_{min}$$

Any short, highly erratic regions in the trace were ignored.

If we consider $Y_o = f(a_o, t_o)$ then each acceptable or unacceptable deceleration defines a region as either acceptable or not when plotted as deceleration versus duration of deceleration.

Case 1: If $f(a_o, t_o)$ is acceptable, then for a time t_o all decelerations from zero to a_o are tolerable. (If the subject can tolerate a_o, he can certainly stand a lesser deceleration.) Furthermore, for a deceleration of a_o, if duration of this deceleration is tolerable for a time t_o, it is certainly tolerable for a lesser period. Thus a minimum region of acceptability is defined as in figure 25.

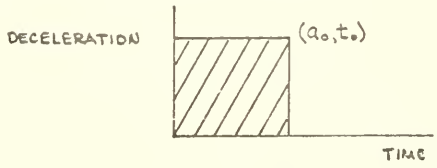


FIGURE 25 MINIMUM REGION OF ACCEPTABLE DECELERATION

We know that velocity = acceleration x time. Thus for a constant release velocity we can certainly tolerate a lesser a_o and a greater t_o, and a hyperbolic curve now theoretically defines the region of acceptability as in figure 26 and 27.

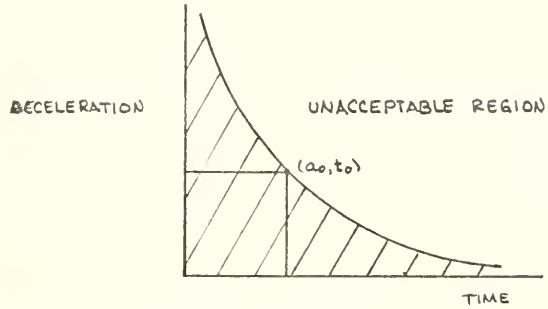


FIGURE 26 THEORETICAL REGION OF ACCEPTABLE DECELERATION

Case 2: Similar arguments can be made for the unacceptable region, which is the area to the outside of the hyperbolic curve found in figure 26.

Conclusions

We recommend that the designers of the moving belt not use our maximum acceptable decelerations, but deceleration slightly less, to provide a margin for experimental error and safety. Also, the people used as test subjects were all college students, hopefully in better physical condition than other people who will be using the belt. Elderly or infirm persons would not be expected to be quite as adaptable.

Our results, very briefly were the following:

* a step change of no more than 1.2 mph is acceptable in the acceleration process, and

* gradual deceleration is acceptable anywhere in the region where a_o (miles per hour per second) x t_o (seconds) is less than one.

Faculty comment--David Wilson

The human tolerance to acceleration while standing on a moving belt, as treated above, was, we considered, one of the most important determinants of the design. Another problem we considered to be critical was the reaction of passengers to falling against a supposedly stationary sidewall of the people-mover while on the high-speed section. Some tests were carried out by towing a subject, suitably padded and protected, on a

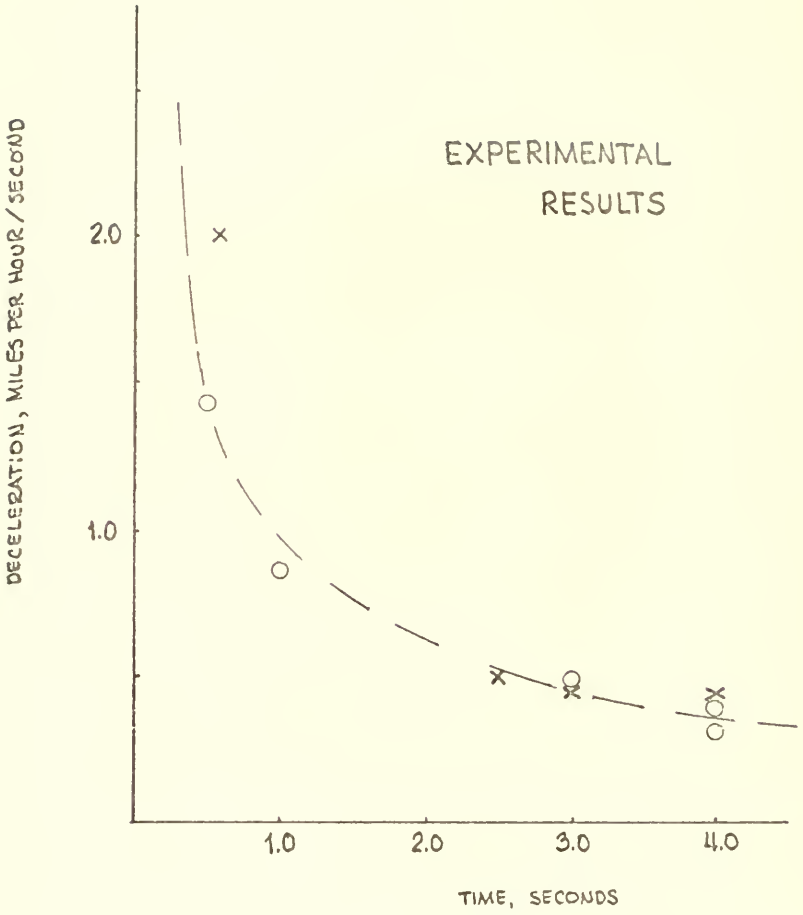


FIGURE 27 EXPERIMENTAL RESULTS OF ACCELERATION TESTS

sheet of plywood behind an automobile and alongside a concrete wall. The subject allowed himself to fall against the wall while being towed at different speeds. In these rather artificial circumstances he felt that 10 mph was a high relative speed for a large proportion of the population. Unless low-friction surfaces could be used on the sidewalls, 7.5 mph seemed more reasonable as a limit.

We have seen reports of no other work on human tests of people-mover accelerators. Exhaustive tests seem to be a critical requirement before a great deal of effort is devoted toward solving the considerable engineering problems associated with accelerating people to high and possibly unacceptable speeds.

PASSENGER-OPERATED SAFETY ALARM

-Neil D. Singer-

Summary

This report describes the design and model construction of a passenger-operated emergency-stop alarm system to work in conjunction with a high-speed convevor-belt system to move people from Columbia MBTA station to other locations on Columbia Point. The alarm system provides a moving ledge about one-inch wide traveling at the same speed as passengers on the belt. In case of emergency, a passenger can pull down on this ledge, and thereby stop the belt. The passenger's pull on the ledge is converted to a displacement within the structure supporting the ledge. This displacement activates an electrical switch, so that the mechanical signal from the passenger is transformed into an electrical signal. The electrical signal can be used to slow the belt to a stop, and also to indicate to emergency personnel the location from which the alarm was sent.

Introduction

The people-mover was designed to operate at high speed (about ten mph) over most of its length. If a personal accident or mechanical failure were to occur, it would be essential to be able to stop the belt. Since such an occurrence would most likely be noticed first by passengers, good sense suggests that the belt be equipped with a passenger-operated automatic stopping system analogous to the pull chain to stop the MBTA trains. However, a stationary safety device on a wall of the people-mover would not be suitable due to the large relative speed between the passengers and the walls. Thus, I was led to the idea of devising an alarm switch which would move with the belt so that passengers would be able to operate the alarm without incurring any risk to their hands. Along this same line of reasoning, the alarm had to be supported in such a way that there was no chance of a passenger's hand getting caught between the moving part of the alarm switch and its supports. Other constraints on the system were:

1 - low maintenance requirements,

2 - high reliability,

3 - an appearance that would not be mistaken for that of a hand hold,

4 - accessibility.

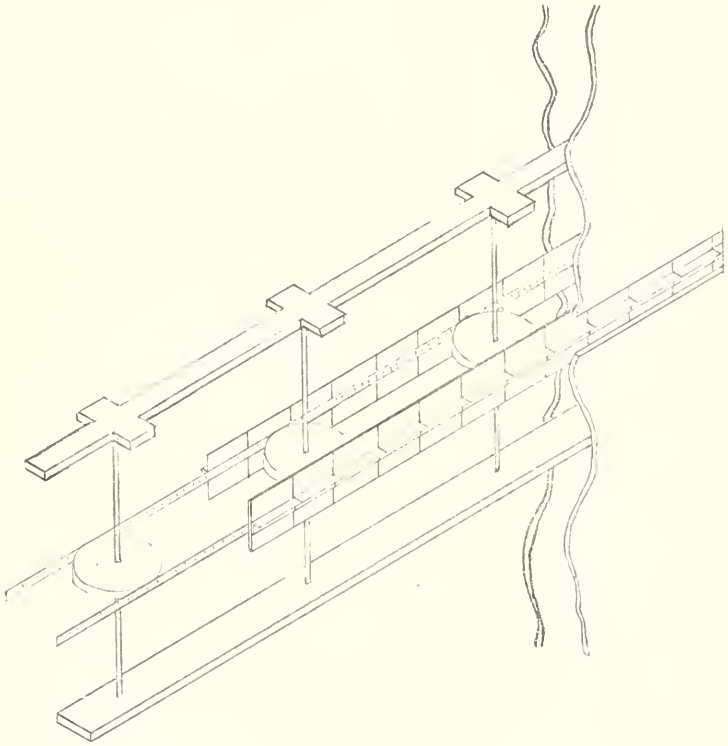


FIGURE 28 CUT-AWAY VIEW OF SAFETY ALARM

Description

With these considerations in mind, I designed a system which would mount high in the center wall (which divides the two directions of travel on the people-mover) and could be operated by passengers going in either direction. The system consists of a belt running in pulleys about one foot in diameter. The pulleys are mounted so that they rotate about vertical axes. Attached to the belt are flat plates which are butted against each other along the length of the belt. The plates form two solid vertical planes enclosing the belt (with the pulleys inside) except at the two drive wheels, where the belt bends sharply from its approximately straight-line path. (This system can easily accommodate the slight bending introduced by curves in the people-mover route.) Attached to each plate is a horizontal ledge, centered vertically but running the complete horizontal length of the plate. The plates run in a guide in the wall so that the pulleys are hidden within the wall. From a passenger's point of view, the system appears to be a moving section of wall several inches wide and running the entire length of the people-mover. This moving section is equipped with a ledge which the passenger can grip with his fingers and pull down on to activate the emergency stopping system. Inside the wall, the support pulleys are tilted when the ledge is pulled down, and this tilting activates an electrical switch which stops the people-mover.

The drawing which preceded this section, and those which follow, illustrate the system just described. The first shows the basic components of the system and their spatial relationships. The second shows the details of the flat plates separating as their support belt bends around a drive wheel at one end of the system. The third drawing illustrates the operation of the switch. Note that the pulley is supported so that it can be rotated in its plane or tilted out of its plane. Ordinarily the weight of the belt is equal on both sides of the pulley. A slight spring force is applied by the switch at the top of the axle, so the pulley stays horizontal. However, a pull from either side moves that edge of the pulley down, thus moving the top of the axle right or left and closing the switch contacts. This switch would then effect the stopping of the people-mover.

Design and construction

In the lab I built a model of the safety-alarm switch. The model was built to illustrate the principles involved and some of the engineering techniques that could be used in producing such a device; however, it was not a true working model, nor was it an accurate scale model. Unlike the actual alarm in the people-mover, the model was not motorized. It could be moved by hand, but provisions for channeling the plates into the guideway in the wall were not made. Thus, the travel of the belt in the model was limited to a few inches unless one manually aligned the plates with the guideway. Many of the details of construction of the model were governed by limitations on manufacturing techniques and material choices. Wear characteristics were largely neglected since nothing could be done about them. However, in a more realistic production situation, all of these shortcomings could easily be corrected.

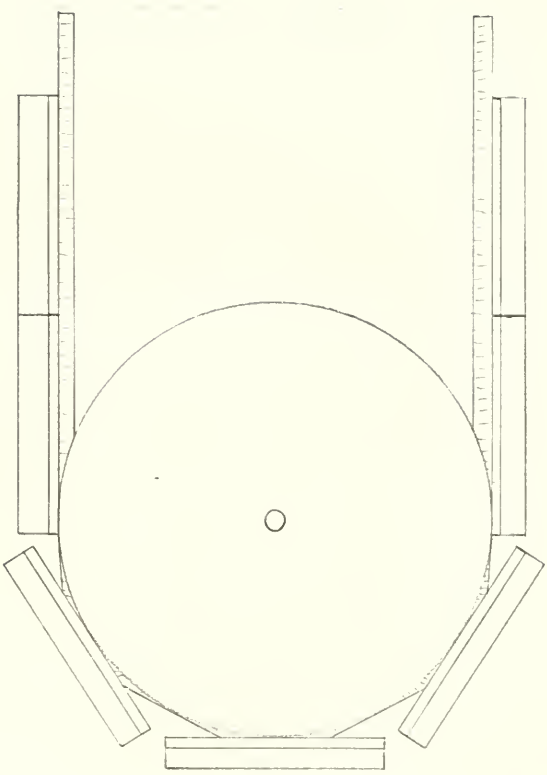


FIGURE 29 FLAT SECTIONS GOING AROUND DRIVE WHEEL

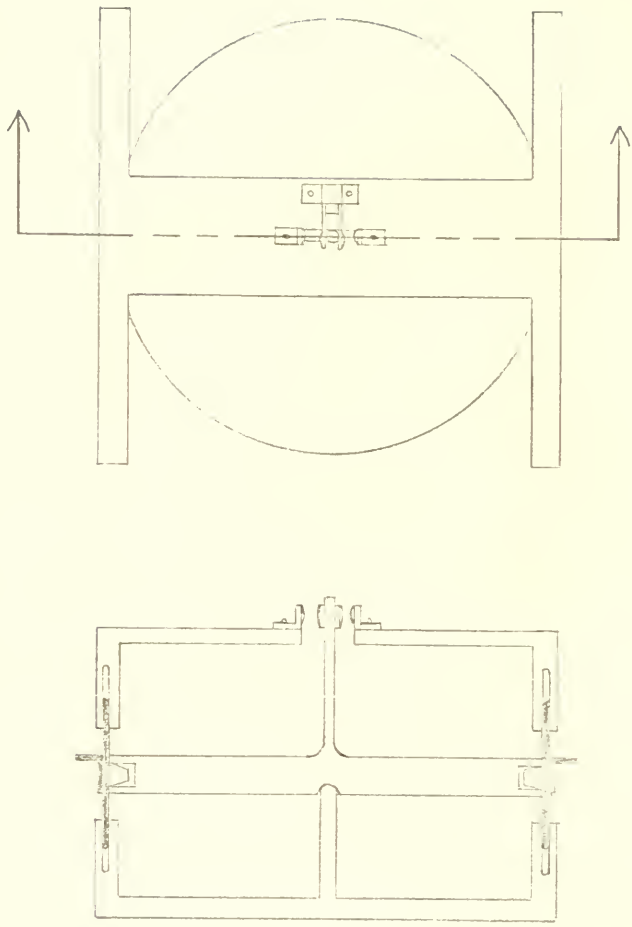


FIGURE 30 CROSS SECTION OF SWITCH MECHANISM

Conclusions and recommendations

My main conclusion from building the model was that the design of the safetv-alarm system presented in this report is basicallv workable. The most serious anticipated problem with the model's operation was the fact that the belt had a tendency to climb out of its groove in the pulleys. This is a typical problem encountered when using narrow belts; in fact, the accelerator for the people-mover used the same-size belts and was also plagued with this problem. Use of v-belts would be better for both the accelerator and the safety-alarm system.

The work which remains to be done falls into two categories: circuitry and pulley spacing. Neither category can be dealt with accurately without building more sophisticated prototvnes of the whole system. To design appropriate stopping circuitry, one would need to know whether the belt would coast to a stop gradually enough, or whether the power to the belt would have to be gradually decreased. Perhaps it would be necessary to apply some sort of braking to stop the belt quickly enough. This information depends on the detailed design of the people-mover, and, thus, would be available only if a more realistic belt is built. The spacing between pullevs in the safety alarm is largelv dependent on the weight of the plates attached to the support belt. Since the plates of the real safety alarm would probably be plastic, and hence of lighter weight, it seems likely that the required pulley spacing would be about three feet. (The model required a pulley every two feet.)

CONCLUSIONS ON THE PROJECT

1 - On the basis of a very simplified engineering cost analysis and passenger-flow estimate, a people-mover seems a more economical and a more attractive solution than a shuttle-bus system to connect the Columbia Point U. Mass. campus to the MBTA rapid-transit line.

2 - Of the possible routes, that down Mt. Vernon Street with a stop at the housing project seems to be the most attractive.

3 - A moving-belt people-mover accelerator with discrete changes in velocity, having abutted belts or interleaved belts seems feasible from the human-acceptability viewpoint and can be easily designed and constructed. However, a moving-seat or separate-vehicle people-mover would, at some increase in costs, provide the potential of greater passenger safety and higher-speed operation.

4 - The expanding-linkage drive system, developed for use as a handrail, has additional promise for propelling a chair or other vehicle and might in itself be the basis of a people-mover system rather than moving belts.

BOSTON PUBLIC LIBRARY
3 9999 06352 240 1

BIBLIOGRAPHY AND REFERENCES

1. "The carveyor, solution to city traffic snarls", bulletin #256 by the Goodyear Tire and Rubber Company, Akron, Ohio.

2. "Elevated pedway", by NRDC & Dunlop Rubber Co., in Engineering, November 29, 1968, Vol. 206, no. 5354, p. 300.

3. "High-speed moving-pavements--some of the human problems", by D. L. Turner, Institution of Mechanicl Engineers, London - conference on rapid-transit vehicles for city services, Paris, November 24-26, 1970

4. New Movement in cities, by Brian Richards; Reinhold Publishing Company, New York, 1969, pp. 57-63.

5. "Personal-transit dual-mode cable cars", by David Gordon Wilson, editor; a report on a term project by students and faculty involved in the Urban Laboratory in Mechanical Engineering, M.I.T. (DSR 72813-1), May 1971.

6. "Role of moving-walks in downtown distribution", by Rick Kuner, chief transportation planner, Boston Redevelopment Authority; ASCE National Meeting on Transportation Engineering, Boston, Massachusetts, July 13-17, 1970 (preprint 1248)

7. "The sixth and final report by the special commission relative to the finances and operation of the Massachusetts Bay Transportation Authority", Commonwealth of Massachusetts, House no. 5580, May 1971.

8. Speedramp/Speedwalk (a division of Goodyear Tire & Rubber Company) brochures:

   a. #AIA - 33 J
   b. #821 - 947 - 226 (November 1970)
   c. #821 - 947 - 201 (March 1970)

Columbia Point M382I
Mass. Institute of Tech.

A Moving-Belt People Mover
for Columbia Point.
June 1972.